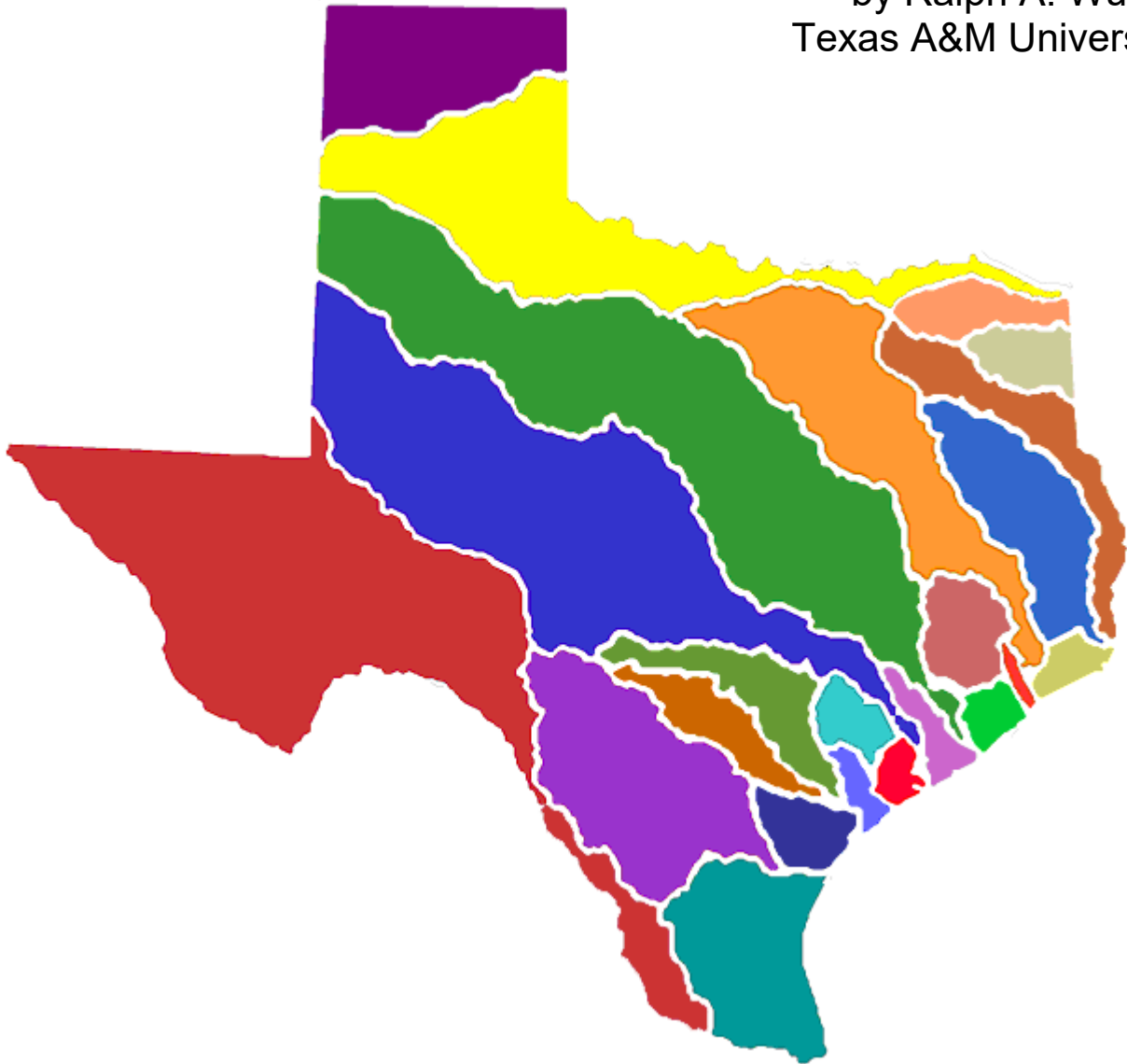


Water Rights Analysis Package (WRAP) Modeling System Reference Manual

by Ralph A. Wurbs
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by

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Dr. Kathy Alexander has served as the TCEQ Project Manager for the WRAP research and development at TAMU for many years along with her responsibilities in administering the TCEQ water rights permit program. Her exemplary leadership in guiding and integrating the efforts of university researchers, agency professionals, consulting engineers, and water managers has greatly contributed to the improvement and effective application of the modeling system.

WRAP input datasets simulating specified alternative water use scenarios for the 23 river basins of Texas were compiled by several consulting engineering firms working for the TNRCC/TCEQ, in coordination with the Texas Water Development Board (TWDB) and Texas Parks and Wildlife Department (TPWD), during development of the WAM System authorized by the 1997 Senate Bill 1. Reports prepared by the consulting firms for the TNRCC/TCEQ documenting development of the WAMs are listed in Appendix A of this *Reference Manual*. The Center for Research in Water Resources at the University of Texas at Austin provided GIS support for this effort. The WRAP software and modeling methods were greatly expanded at TAMU based on the experience gained by the water management professionals of these agencies and consulting firms and their ideas for model improvements.

Since the initial implementation of the Texas WAM System during 1997-2002, the agencies and consulting firms have continued to employ the modeling system in support of the water rights permitting process, regional and statewide planning, and other water management activities. The TCEQ has sponsored continued WRAP expansion and improvement in close coordination with the Texas water management community. The experience base and concepts for improvements generated by the professional community continue to greatly contribute to improving WRAP/WAM capabilities.

Many agencies, firms, and individuals have contributed to development and improvement of WRAP. The original model called TAMUWRAP was created during a 1986-1988 research project at TAMU, entitled *Optimizing Reservoir System Operations*, funded by a federal/state cooperative research program administered by the U.S. Geological Survey (USGS) and Texas Water Resources Institute (TWRI). The Brazos River Authority (BRA) served as a nonfederal sponsor. Major improvements in the modeling system were accomplished during 1990-1994 in conjunction with TAMU research projects sponsored by the TWDB through the TWRI and by the Texas Advanced Technology Program administered by the Texas Higher Education Coordinating Board. The National Institute for Global Environmental Change of the U.S. Department of Energy funded research at TAMU during 1998-2003 that involved application of

WRAP in assessments of the impacts of climate change on water management. The U.S. Army Corps of Engineers Fort Worth District during 2001-2005 also sponsored continued development of WRAP modeling capabilities. The TWDB and BRA sponsored additional improvements during 2007-2008 and 2008-2011, respectively. TAMU AgriLife Research and Extension funded work during 2013-2015 expanding WRAP conditional reliability modeling (CRM) capabilities for supporting agricultural irrigation management.

Many graduate students at Texas A&M University have employed WRAP in courses and research projects. The following former students worked as funded research assistants focusing their thesis or dissertation research on WRAP related topics and contributing to improving the modeling system or devising strategies for diverse applications of the modeling system: W. Brian Walls, M.S. 1988; David D. Dunn, M.S. 1993; Anilkumar R. Yerramreddy, M.S. 1993; Gerardo Sanchez-Torres, Ph.D. 1994; Emery D. Sisson, M.S. 1999; A. Andres Salazar, Ph.D. 2002; Hector E. Olmos, M.S. 2004; Ganesh Krishnamurthy, M.S. 2005; Mi Ae Ha, M.S. 2006; Tae Jin Kim, Ph.D. 2009; Spencer T. Schnier, M.S. 2010; Chihun Lee, Ph.D. 2010; Richard J. Hoffpauir, Ph.D. 2010; Mark A. Pauls, M.S. 2014; Mustafa Demirel, M.S. 2015; Ankit Bista, M.S. 2015; Minkyu Ryu, Ph.D. 2015; Askarali Karimov, Ph.D., 2016; Mingyue Yang, M.S. 2016; Camilo Christancho, M.S. 2017; Vivek Verma, M.S. 2017; M. Abdul Siddiqui, M.S. 2017; Gunil Chun, Ph.D., 2018; Cemil Arslan, M.S. 2019; and Yiwen Zhang, M.S. 2014 and Ph.D, 2019. Their theses and dissertations are listed in Appendix A of this *Reference Manual*.

David D. Dunn, P.E., contributed to the evolution of WRAP since the early 1990's, initially as a graduate student at TAMU, followed by an employment period at the USGS, and since then at HDR Engineering participating in the TCEQ WAM System development and later in various planning and research studies. Richard J. Hoffpauir, Ph.D., P.E., has also worked for many years both at TAMU in research and development to expand WRAP capabilities and as a consultant applying the modeling system.

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CHAPTER 1 INTRODUCTION

The WRAP modeling system simulates management of the water resources of a river basin or region under priority-based water allocation systems (<https://wrap.engr.tamu.edu/>). In WRAP terminology, river/reservoir system water management requirements and capabilities are called water rights. The modeling system facilitates assessments of hydrologic and institutional water availability and reliability in satisfying requirements for instream flows, water supply diversions, hydroelectric energy generation, and reservoir storage. Reservoir system operations for flood control can be simulated. Capabilities are also provided for tracking salinity loads and concentrations. Basin-wide impacts of water resources development projects and management practices are modeled. The modeling system is generalized for application anywhere, with input datasets being developed for the particular river basins of concern.

WRAP is incorporated in the Water Availability Modeling (WAM) System implemented and maintained by the Texas Commission on Environmental Quality (TCEQ). The TCEQ WAM System includes databases of water rights and related information, geographical information system (GIS) and other data management software, and WRAP input files and simulation results for the 23 river basins of Texas, as well as the generalized WRAP. The WRAP modeling system may be applied either independently of or in conjunction with the Texas WAM System. The set of reports documenting WRAP, including this *Reference Manual*, focus on the generalized WRAP, rather than the overall Texas WAM System.

WRAP simulation studies combine a specified scenario of river/reservoir system management and water use with river basin hydrology represented by sequences of naturalized stream flows and reservoir evaporation-precipitation rates at pertinent locations for each monthly or daily interval of a hydrologic period-of-analysis. Model application consists of:

1. compiling water management and hydrology input data for the river system
2. simulating alternative water resources development, management, and use scenarios
3. developing water supply reliability and stream flow and storage volume frequency relationships and otherwise organizing and analyzing simulation results

Input datasets for the river basins of Texas are available through the TCEQ WAM System. WRAP users modify these data files to model the alternative water resources development projects, river regulation strategies, and water use scenarios being investigated in their studies. For applications outside of Texas, model users must develop their own input datasets.

WRAP Documentation

Numbers in brackets found throughout this manual refer to the list of references on pages 365-367, which lists the publications that are cited in the manual. Other relevant publications not actually cited in this manual are included in the bibliography compiled in Appendix A.

This *Reference Manual* describes the concepts and methods employed in WRAP, focusing on monthly modeling. Expanded capabilities of the daily modeling system are covered in the *Daily Manual*. The *Users Manual* provides instructions for applying the main programs. The four other manuals listed below serve specific purposes that are described as follows.

Water Rights Analysis Package (WRAP) Modeling System Reference Manual, TWRI TR-255, 14th Edition, July 2022. (*this Reference Manual*) [1]

Water Rights Analysis Package (WRAP) Modeling System Users Manual, TWRI TR-256, 14th Edition, July 2022. (*Users Manual*) [2]

Fundamentals of Water Availability Modeling with WRAP, TWRI TR-283, Tenth Edition, July 2022. (*Fundamentals Manual*) [3]

Water Rights Analysis Package (WRAP) Daily Modeling System, TWRI TR-430, Fourth Edition, July 2022. (*Daily Manual*) [4]

Water Rights Analysis Package (WRAP) River System Hydrology, TWRI TR-431, Third Edition, May 2019. (*Hydrology Manual*) [5]

Salinity Simulation with WRAP, TWRI TR-317, July 2009. (*Salinity Manual*) [6]

Water Rights Analysis Package (WRAP) Programming Manual, TWRI TR-388, Eighth Edition, July 2022. (*Programming Manual*) [7]

The TCEQ WAM System was implemented during 1997-2003 based on the WRAP modeling capabilities covered by this *Reference Manual* and accompanying *Users Manual*. These two primary manuals cover the WRAP modeling features reflected in the original and updated WAM System datasets plus various enhancements. Modeling capabilities documented by the basic *Reference* and *Users Manuals* are designed for assessing water availability for existing and proposed water rights under alternative water management and use scenarios based on a hydrologic simulation period covering many years with a monthly computational time step.

The *Fundamentals Manual* is designed as an introductory tutorial allowing new users to learn the basics of the modeling system quickly. With this abbreviated manual covering only select basic features, within a few hours, first-time users can become proficient in fundamental aspects of applying WRAP. The other manuals and experience in applying the modeling system are required for proficiency in implementing broader ranges of modeling options.

WRAP applications range from simple to quite complex. Complexities are due primarily to requirements for flexibility in modeling diverse water management strategies and reservoir/river system operating practices, extensive physical infrastructure, and complex institutional systems allocating water between numerous water users. Modeling flexibility is provided through many optional features that are documented in detail in the *Reference*, *Users*, *Daily*, *Hydrology*, and *Salinity Manuals*. However, easy-to-learn fundamentals covered in the *Fundamentals Manual* account for a significant portion of practical modeling applications.

The *Reference*, *Users*, and *Fundamental Manuals* describe the monthly *SIM* simulation model and corresponding features of the post-simulation programs *TABLES* and *HEC-DSSVue*. The *Daily Manual* describes *SIMD* which provides daily simulation capabilities that include environmental flow requirements and flood control reservoir operations and corresponding daily features of *TABLES*. The *Hydrology Manual* documents capabilities provided by program *HYD* to develop and update monthly naturalized stream flow and net reservoir surface evaporation-precipitation sequences for input to *SIM*. The *Salinity Manual* covers the salinity tracking capabilities of *SALT* and salinity-related features of *TABLES*. The *Programming Manual* facilitates modifying the Fortran programs but is not needed for applying the modeling system.

WRAP Programs

WRAP is a set of computer programs. Executable files are available for use with Microsoft Windows. Recent versions of the Fortran programs have been compiled with the Intel Visual Fortran compiler within the Microsoft Visual Studio Integrated Development Environment for execution with 64-bit architecture. The code conforms to the latest Fortran standards. A *Programming Manual* [7] provides information useful in examining or modifying the Fortran code but is not necessary for applying the modeling system. A periodically updated report documents the history of program modifications [8]. The public domain executable programs and documentation may be freely copied. Table 1.1 summarizes the function of each program and indicates whether it is documented by this *Reference Manual* and accompanying *Users Manual* or by the previously cited auxiliary manuals covering expanded modeling capabilities.

Table 1.1
WRAP Programs

Program	Filename	Function	Manuals
WinWRAP	WinWRAP.exe	Microsoft Windows interface	Users & Fundamentals
TABLES	TAB.exe	Post-simulation summary tables, reliability indices, frequency tables	Reference, Users, Fund, Daily, Salinity Manuals
SIM	SIM.exe	Monthly simulation model	Reference, Users, Fund
SIMD	SIMD.exe	Daily simulation model	Daily & Users Manuals
SALT	SALT.exe	Salinity simulation model	Salinity Manual
HYD	HYD.exe	Monthly hydrology data	Hydrology Manual
DAY, DAYH	DAY.exe	Daily hydrology data	Daily Manual

This *Reference Manual* and the *Fundamentals Manual* focus on the first three computer programs listed in Table 1.1. The *Users Manual* covers *SIMD* as well as *SIM* and *TABLES*.

WinWRAP facilitates execution of the WRAP programs within the Microsoft Windows environment along with Microsoft programs and *HEC-DSSVue*.

SIM simulates the river/reservoir water allocation/management/use system for input sequences of monthly naturalized flows and net evaporation rates.

TABLES develops frequency relationships, reliability indices, and various user-specified tables for organizing, summarizing, and displaying simulation results.

SIMD (*D* for daily) is an expanded daily computational time step version of *SIM* that adds flow disaggregation, flow forecasting and routing, environmental pulse flows, and flood control operations along with all of the capabilities of *SIM*.

The following programs supplement and/or expand the basic monthly modeling system comprised of the programs listed above. The following programs are introduced in the *Reference and Users Manuals* and documented in detail by the auxiliary manuals noted in Table 1.1.

HYD assists in developing and updating monthly naturalized stream flow and reservoir net evaporation-precipitation depth data for the *SIM* hydrology input files.

DAY and *DAYH* assist in calibrating routing parameters and otherwise developing daily time step hydrology input for *SIMD*.

SALT reads a *SIM* or monthly *SIMD* output file and a salinity input file and tracks salt constituents through the river/reservoir/water use system.

WinWRAP User Interface

WRAP users create or obtain previously created files describing hydrology and water management for the river basin or region of concern along with other related information. The programs are connected through various input/output files. Certain programs create files with intermediate results to be read by other programs. File access occurs automatically, controlled by the software. WinWRAP provides a framework for working with the programs and data files.

The Fortran programs are compiled as separate individual programs that may be executed without using *WinWRAP*. However, the *WinWRAP* user interface program facilitates running the WRAP programs within Microsoft Windows in an integrated manner along with use of Microsoft programs to access and edit input and output files and use of *HEC-DSSVue* to plot and/or otherwise analyze simulation results. The *WinWRAP* interface connects executable programs and data files.

SIM and SIMD Versions of the Simulation Model

The simulation program *SIM* performs the river/reservoir/use system water allocation computations using a monthly time step. The daily *SIMD* contains all of the capabilities of the monthly time step *SIM*, plus options for synthesizing daily time step stream flows, flow forecasting and routing, and simulating pulse environmental flows and reservoir operations for flood control. *SIMD* duplicates simulation results for datasets prepared for *SIM*. The *SIM* program is complex, and the additional features make *SIMD* significantly more complex. *SIM* has been applied extensively as a component of the TCEQ WAM System. *SIMD* has become fully operational only recently.

The *SIMD* daily computational time step, disaggregation of monthly to daily naturalized flows, daily water use target setting, pulse flow components of environmental flow targets, flow forecasting, flow routing, and flood control reservoir operations features covered in the *Daily Manual* are provided only by *SIMD*, not *SIM*. *SIMD* flow forecasting involves consideration of future stream flows over a specified forecast period in making water supply diversion, flood control, and other multiple-purpose reservoir system operating decisions. Routing methodologies model translation and attenuation of stream flow adjustments. The post-simulation program *TABLES* works with either monthly or daily *SIM* or *SIMD* simulation results.

HYD, DAY, and DAYH Pre-Simulation Hydrology Programs

Program *HYD* described in the *Hydrology Manual* provides routines for developing and updating hydrology input for *SIM*, which consists of sequences of monthly naturalized stream flows and reservoir net evaporation-precipitation rates. *HYD* can be used both in developing new hydrology datasets and updating the hydrologic period-of-analysis of existing datasets.

The primary function of the programs *DAY* and *DAYH* documented in the *Daily Manual* is calibration of daily flow routing parameters but other optional computational routines are also provided to facilitate developing daily *SIMD* hydrology input. The recently created *DAY* and older *DAYH* provide different alternative approaches for determining values of routing parameters.

SALT Simulation Model

The program *SALT* is applied in combination with either *SIM* or *SIMD* to simulate salinity. *SALT* is designed for use with a monthly time step. *SALT* obtains monthly water quantities by reading the main *SIM* or *SIMD* output file, obtains water quality data by reading a separate salinity input file, and tracks the water quality constituents through the river/reservoir system. All of the simulation capabilities of *SIM/SIMD* are preserved while adding salt balance accounting features.

TABLES Organization of Simulation Results

The program *TABLES* provides a comprehensive array of tables and tabulations in user-specified formats for organizing, summarizing, analyzing, and displaying simulation results from *SIM*, *SIMD*, and *SALT*. Many of the options provided by *TABLES* involve rearranging simulation results into convenient tables for reports and analyses or as tabulations for export to Microsoft Excel or *HEC-DSSVue*. *TABLES* also provides an assortment of computational options for developing tables of water supply reliability indices and flow and storage frequency relationships.

Hydrologic Engineering Center (HEC) Data Storage System (DSS)

The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE) has developed a suite of generalized hydrologic, hydraulic, and water management simulation models that are applied extensively by numerous agencies and consulting firms throughout the United States and abroad. The HEC-DSS (Data Storage System) is used routinely with HEC simulation models and with other non-HEC modeling systems including WRAP to manage time series datasets. Multiple simulation models share the same time series data management software that also includes graphics and a set of routines for statistical analysis and mathematical operations.

HEC-DSS and the *HEC-DSSVue* component of HEC-DSS are fully integrated with WRAP. The WRAP Fortran programs are linked during compilation to DSS routines from a static library developed by the Hydrologic Engineering Center that allow creating and accessing binary DSS files. WRAP executable programs include options for writing *SIM*, *SIMD*, and *SALT* simulation results as DSS files. Hydrology time series stored as a DSS file are read by the WRAP simulation programs. The WRAP programs *TABLES*, *HYD*, and *DAY* also read and create DSS files.

The *HEC-DSS Visual Utility Engine (HEC-DSSVue)* is a user interface for viewing, organizing, editing, and plotting data in DSS files and performing mathematical operations and statistical analyses. The public domain *HEC-DSSVue* software and detailed *User's Manual* [9] may be downloaded from the Hydrologic Engineering Center website: <http://www.hec.usace.army.mil/>. *HEC-DSSVue* provides convenient capabilities for compiling, storing, managing, searching, and displaying time series of WRAP *SIM* and *SIMD* hydrology input datasets and simulation results, and also includes graphics and mathematical and statistical computational analyzes. WRAP uses of DSS and *HEC-DSSVue* are described in Chapter 6 of the *WRAP Users Manual* [2].

Other Auxiliary Software

The WRAP programs provide comprehensive computational capabilities but have no editing or graphics capabilities. The USACE Hydrologic Engineering Center's HEC-DSSVue provides comprehensive capabilities for compiling, viewing, and editing time series datasets. The user's choice of software may be adopted for use in viewing and editing WRAP text files. The only required auxiliary software is an editor such as Microsoft WordPad. However, WRAP modeling and analysis capabilities are enhanced by use of other supporting software for developing and managing datasets, such as Microsoft Excel and ESRI ArcGIS.

Microsoft Programs and NotePad++

Microsoft Wordpad, Word, and Notepad or the public domain Notepad++ are used routinely in creating and editing WRAP input files and viewing and reporting simulation results as discussed in the *Users* and *Fundamentals Manuals*. Microsoft Excel provides both graphics and computational capabilities and has been extensively applied with WRAP. *TABLES* has options for tabulating essentially any of the time series variables included in the *SIM*, *SIMD*, and *SALT* simulation results in a format designed to be conveniently accessed by Microsoft Excel for plotting or other purposes.

ArcGIS and ArcMap WRAP Display Tool

Geographic information systems (GIS) such as ESRI's ArcGIS (<http://www.esri.com>) are useful in dealing with spatial aspects of compiling WRAP input data and displaying simulation results. An ArcGIS tool for displaying WRAP simulation results was initially developed at Texas A&M University [10] and subsequently expanded at the University of Texas Center for Research in Water Resources [11] for the TCEQ. The WRAP Display Tool functions as a toolbar within the ArcMap component of ArcGIS. Ranges of water supply reliabilities, flow and storage frequencies, and other simulation results are displayed by control point sites as a color coded map. Customization capabilities as well as standard output data features are provided.

Texas WAM System

Senate Bill 1, Article VII of the 75th Texas Legislature in 1997 directed the Texas Natural Resource Conservation Commission (TNRCC) to develop water availability models for the 22 river basins of the state, excluding the Rio Grande. Subsequent legislation authorized modeling of the Rio Grande Basin. The TNRCC was renamed the Texas Commission on Environmental Quality (TCEQ) in 2002. The Water Availability Modeling (WAM) System was implemented collaboratively by the TCEQ (as lead agency), Texas Water Development Board (TWDB), Texas Parks and Wildlife Department (TPWD), consulting engineering firms, and universities, in coordination with the water management community. The resulting WAM System includes databases and data management systems, WRAP, and WRAP input datasets and simulation results for all of the river basins of Texas [12, 13, 14, 15]. The generalized WRAP modeling system with a dataset for a particular river system is called a water availability model (WAM).

During 1997-1998, the TNRCC, TWDB, TPWD, and a team of consulting firms evaluated available river/reservoir system simulation models to select a generalized model to

adopt for the statewide water availability modeling system. This study resulted in adoption of WRAP, along with recommendations for modifications. WRAP has been greatly expanded and improved during 1997-2003 and 2005-2019 at Texas A&M University under interagency agreements between the TCEQ and Texas A&M University System.

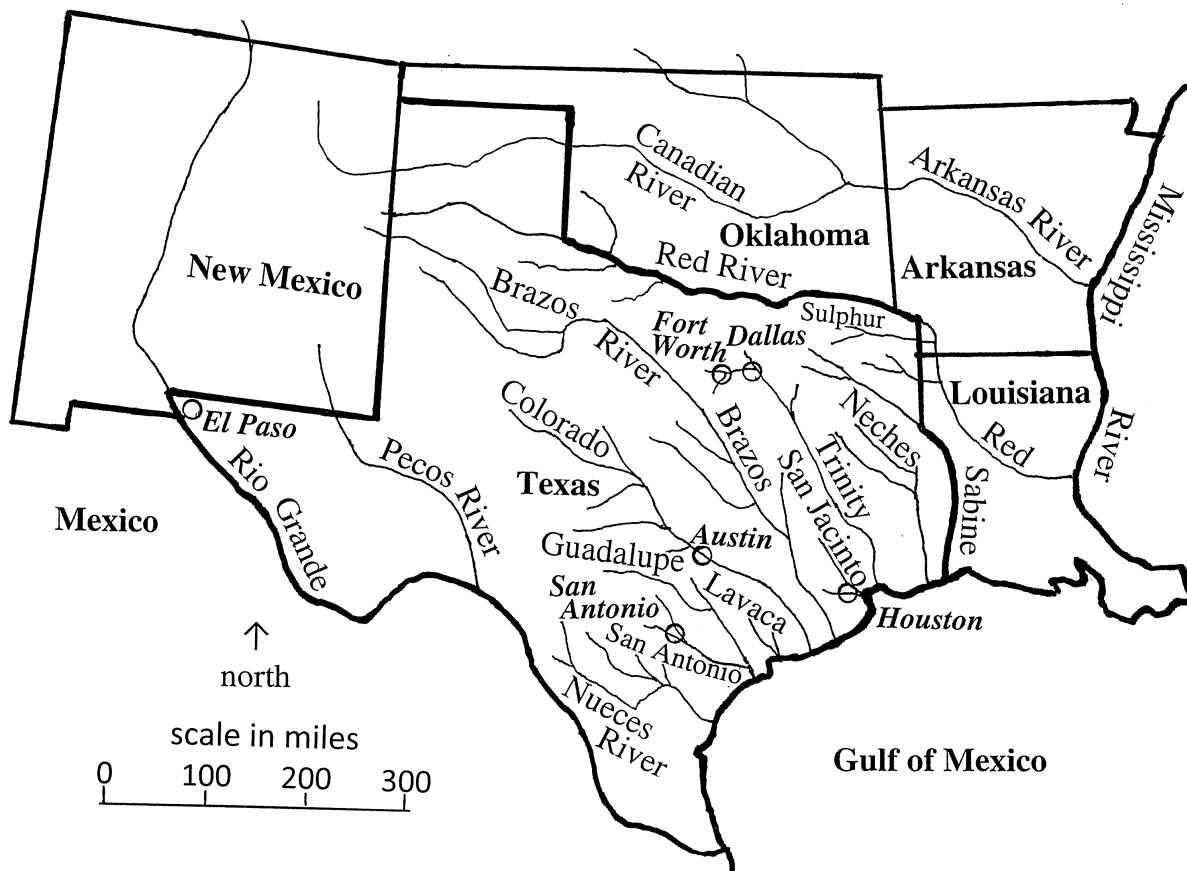


Figure 1.1 Major Rivers and Largest Cities in Texas

Consulting engineering firms working under contracts with the TNRCC/TCEQ developed WRAP input datasets and performed simulation studies for all of the river basins of the state during 1998-2003. These studies are documented by the WAM reports listed in the bibliography in Appendix A. Individual engineering firms or teams of firms modeled individual river basins or groups of adjacent basins. Upon completion of the water availability models (WAMs), water rights permit holders were provided information regarding reliabilities associated with their water rights. The publically available WRAP input datasets for all of the Texas river basins are maintained and periodically updated by the TCEQ.

The Center for Research in Water Resources (CRWR) at the University of Texas, under contract with the TCEQ, developed a geographic information system for delineating the spatial connectivity of pertinent sites and determining watershed parameters required for distributing naturalized stream flows [16, 17]. The CRWR applied the GIS to the various river basins and provided the resulting information to the TCEQ and consulting firms responsible for modeling each of the river basins.

Along with compiling the WRAP input datasets, the TCEQ contractors performed simulations for from eight to eleven alternative scenarios reflecting combinations of premises regarding water use, return flows, and reservoir sedimentation. Full authorization and current conditions simulations continue to be routinely adopted for perpetual and term, respectively, water right permit applications and amendments thereto.

- The full authorization scenario is based on the following premises.
 1. Water use targets are the full amounts authorized by the permits.
 2. Full reuse with no return flow is assumed.
 3. Reservoir storage capacities are those specified in the permits, which typically reflect no sediment accumulation.
 4. Only perpetual permits are included. Term permits are not included.
- The current conditions scenario is based on the following premises.
 1. The water use target for each right is based on the maximum annual amount used in any year during a recent ten year period.
 2. Best estimates of actual return flows are adopted.
 3. Reservoir storage capacities and elevation-area-volume relations for major reservoirs reflect sedimentation subject to data availability.
 4. Both perpetual and term permits are included.

Texas has 15 major river basins and eight coastal basins lying between the lower reaches of the major basins as shown in Figure 1.2. The WAM System includes the 20 WRAP input datasets listed in Table 1.2 covering the 23 river basins. Three of the 20 datasets each combine two basins. The latest updates of these datasets are available at the TCEQ WAM website.

Several of the river systems are shared with neighboring states. The Rio Grande is shared with Mexico. For the interstate and international river basins, hydrology and water management in neighboring states and Mexico are considered to the extent necessary to assess water availability in Texas. The models reflect two international treaties and five interstate compacts as well as the two Texas water rights systems administered by the TCEQ. The water rights system allocating the Texas share of the waters of the lower Rio Grande is significantly different from the water rights system for the rest of Texas [18].

The totals in Table 1.2 show that naturalized flows for 500 primary control points are included in the input datasets for the *SIM* simulation model in FLO files and distributed to over 13,000 secondary control points within the simulation based on information provided in DIS files. Table 1.2 also lists the number of control points in each of the 20 datasets for which reservoir net evaporation-precipitation rates are input in EVA files and flow adjustments are input in FAD files.

As of 2014, about 6,200 active water right permits were modeled with 10,581 water right (WR) and 805 instream flow (IF) records in the 20 full authorization scenario datasets listed in Table 1.2 [19]. Current conditions scenario counts are also tabulated. The datasets include the over 3,000 reservoirs with water right permits. The 80 reservoirs with conservation storage capacities exceeding 50,000 acre-feet account for about 92% of the permitted capacity [19]. TCEQ updates the datasets as applications for new permits or revisions to existing permits are approved.

Table 1.2
 Number of Control Points, Water Rights, and Reservoirs in the WAMs in 2014 [19]

WAM	Version for this Table	Scenario	Number of Control Points				WR Records	IF Records	Reservoirs
			Total	FLO	EVA	FAD			
Brazos and SJ-B Coastal	Sep 2008	authorized	3,842	77	67	0	1,643	122	678
	Sep 2008	current	3,852	77	67	0	1,734	145	719
Canadian	Jan 2013	authorized	85	12	9	0	56	0	47
	Jan 2013	current	85	12	9	0	56	0	47
Colorado and B-C Coastal	Mar 2010	authorized	2,422	45	48	20	2,006	99	518
	Aug 2007	current	2,396	45	47	20	1,928	93	510
Cypress	Jan 2010	authorized	147	10	11	0	163	1	91
	Jan 2010	current	147	10	10	0	159	1	91
GSA	Oct 2008	authorized	1,338	46	11	5	848	200	238
	Oct 2008	current	1,340	46	13	5	872	214	241
Lavaca	Nov 2010	authorized	185	8	7	0	70	30	22
	Nov 2010	current	184	8	7	0	65	30	21
Neches	Oct 2012	authorized	378	20	12	0	399	75	180
	Sep 2012	current	395	20	12	0	385	78	203
Nueces	Jan 2013	authorized	543	41	10	0	374	30	121
	Jan 2013	current	546	41	10	0	393	32	125
Red	Jan 2013	authorized	448	47	40	5	507	102	247
	Jan 2013	current	451	47	40	12	508	111	248
Rio Grande	Jun 2007	authorized	957	55	25	1	2,584	4	113
	Jun 2007	current	957	55	25	1	2,597	4	113
Sabine	Aug 2007	authorized	387	27	20	0	321	22	212
	Aug 2007	current	387	27	20	0	328	23	213
San Jacinto	Nov 2009	authorized	412	17	4	0	150	15	114
	Nov 2009	current	414	17	4	0	158	17	114
Sulphur	Nov 2012	authorized	84	8	4	0	83	10	57
	Nov 2012	current	89	8	4	0	85	10	57
Trinity	Oct 2012	authorized	1,398	40	50	0	1,061	71	697
	Oct 2012	current	1,418	40	50	0	1,067	89	700
Colorado-Lavaca	Jul 2007	authorized	111	1	1	0	27	4	8
	Jul 2007	current	111	1	1	0	27	4	8
Lavaca-Guadalupe	Oct 2001	authorized	68	2	2	0	10	0	0
	Oct 2001	current	68	2	2	0	12	0	0
Neches-Trinity	Jan 2013	authorized	249	4	4	0	139	11	31
	Jan 2013	current	249	4	4	0	139	11	31
Nueces-Rio Grande	Jan 2013	authorized	200	29	5	0	104	7	64
	Jan 2013	current	200	29	5	0	109	7	65
San Antonio-Nueces	Jan 2013	authorized	53	9	3	0	12	2	9
	Jan 2013	current	53	9	3	0	12	2	9
Trinity-San Jacinto	Jan 2013	authorized	94	2	3	0	24	0	13
	Jan 2013	current	94	2	3	0	26	1	13
Totals		authorized	13,401	500	336	31	10,581	805	3,460
		current	13,436	500	336	38	10,660	872	3,528

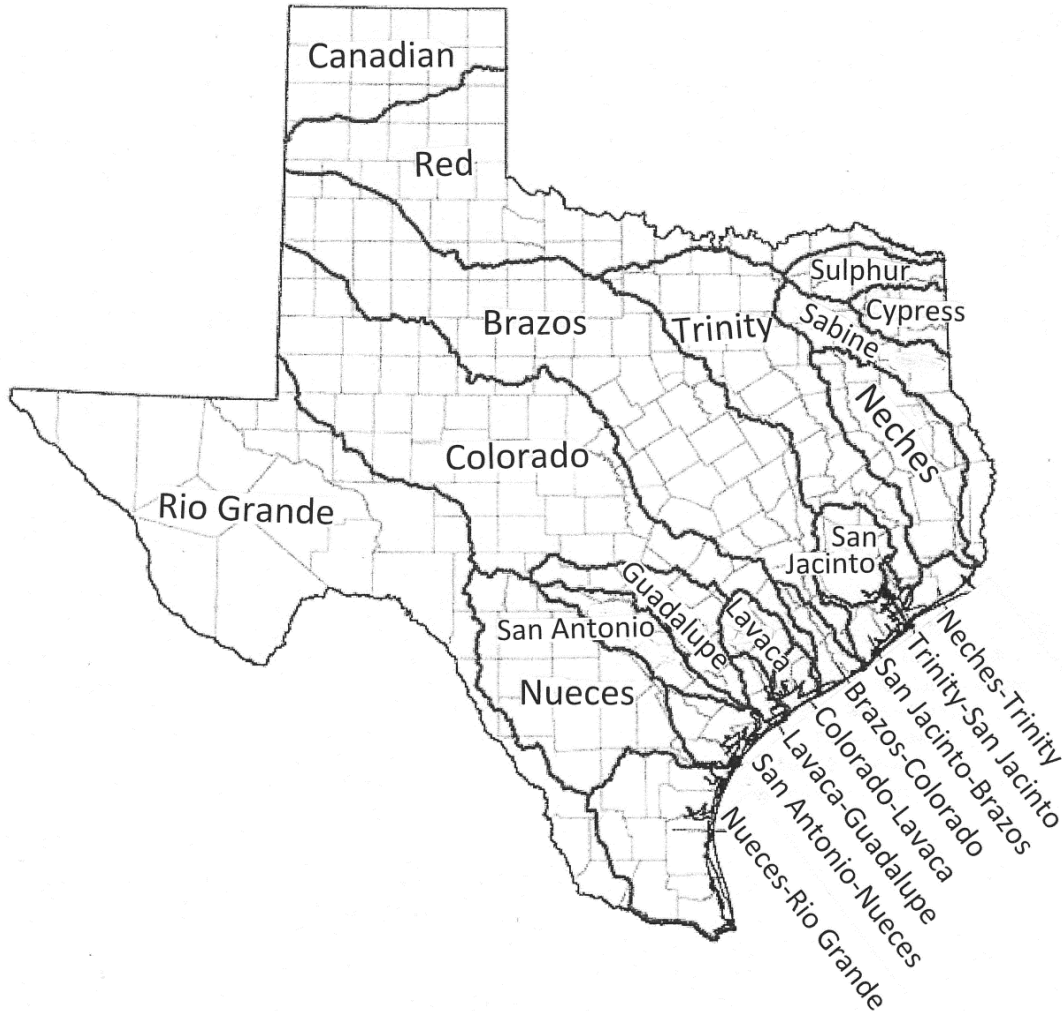


Figure 1.2 Texas River Basins

The WAM System is applied by water right permit applicants and their consultants in preparation of water right permit applications. TCEQ staff applies the modeling system in evaluating the permit applications. The TWDB, regional planning groups, and their consultants apply the modeling system in regional and statewide planning studies also established by the 1997 Senate Bill 1. Agencies, consulting firms, and university researchers use the modeling system in operational planning studies and various other types of studies.

Model Development Background

The primary objectives guiding development of the WRAP modeling system have been:

- to provide capabilities for assessing hydrologic and institutional water availability and reliability within the framework of the priority-based Texas water rights system
- to develop a flexible generalized computer modeling system for simulating the complexities of surface water management, which can be adapted by water management agencies and consulting firms to a broad range of applications

Early Versions of the WRAP Programs

A university research project, entitled *Optimizing Reservoir Operations in Texas*, was performed in 1986-1988 as a part of the cooperative federal/state research program of the Texas Water Resources Institute and U.S. Geological Survey. The Brazos River Authority served as the nonfederal sponsor. The research focused on formulating and evaluating storage reallocations and other reservoir system operating strategies and developing improved modeling capabilities for analyzing hydrologic and institutional water availability. A system of 12 reservoirs in the Brazos River Basin, operated by the U.S. Army Corps of Engineers Fort Worth District and the Brazos River Authority, provided a case study. Several computer simulation models were applied. The need for a generalized water rights analysis model became evident. The original version of the WRAP model, called the *Texas A&M University Water Rights Analysis Program (TAMUWRAP)*, was developed and applied in simulation study of a reservoir system in the Brazos River Basin operated by the USACE and Brazos River Authority [20, 21, 22].

WRAP2 and *WRAP3* along with *TABLES* became the second and third generations of *TAMUWRAP*. These programs and *WRAPNET* and *WRAPSALT* cited next were developed during 1990-1994 in conjunction with research projects sponsored by the Texas Water Resources Institute (TWRI), Texas Water Development Board (TWDB), U.S. Geological Survey (USGS), and the Texas Advanced Technology Program administered by the Texas Higher Education Coordinating Board. These studies focused on natural salt pollution, water rights, and reservoir system operations.

The original *TAMUWRAP* was replaced by *WRAP2* and *TABLES*, reflecting significant improvements building on the same fundamental concepts [23, 24]. The computational algorithms were refined, additional capabilities were added, the input data format was changed, and the output format was totally restructured. *WRAP3* was more complex than *WRAP2* and provided expanded capabilities, particularly in regard to simulating multiple-reservoir, multiple-purpose reservoir system operations. The revisions involved coding completely new computer programs. The USACE/BRA reservoir system in the Brazos River Basin continued to serve as a case study for model development, testing, and application.

WRAPNET was developed in a research study of the relative advantages and disadvantages of adopting a generic network flow programming algorithm for WRAP as compared to ad hoc algorithms developed specifically for WRAP [25]. Network flow programming is a special computationally efficient form of linear programming that has been adopted for a number of other similar models. *WRAPNET* reads the same input files as *WRAP2* and provides the same output, but the simulation computations are performed using a network flow programming algorithm. *TABLES* is used with *WRAPNET* identically as with *WRAP2* or *WRAP3* or the later *WRAP-SIM*. Although network flow programming was demonstrated to be a viable alternative modeling approach, the model-specific algorithms were concluded to be advantageous for the WRAP model.

Development of *WRAP-SALT* was motivated by natural salt pollution in Texas and neighboring states [26]. The model was applied to the Brazos River Basin. The initial *WRAP-SALT* was an expanded version of *WRAP3* and *TABLES* with features added for simulating salt concentrations and their impacts on supply reliabilities [24]. Sequences of monthly salt loads were input along with the naturalized stream flows. Water availability was constrained by both salt concentrations and water quantities. The current *SALT* provides similar modeling capabilities but

has been completely rewritten [6]. Whereas the original *WRAP-SALT* integrated the salinity computations internally within *WRAP3* creating a separate program, the current *SALT* is a companion program that reads a *SIM* output file along with a salinity input file.

Texas WAM System

Development of WRAP was motivated by implementation of a water rights permit system in Texas during the 1970's and 1980's and creation of the previously discussed statewide Water Availability Modeling (WAM) System during 1997-2003 to support administration of the water rights system. Surface water law in Texas evolved historically over several centuries [18]. Early water rights were granted based on versions of the riparian doctrine. A prior appropriation system was later adopted and then modified. The Water Rights Adjudication Act of 1967 merged the riparian water rights into the prior appropriation system. The allocation of surface water was consolidated into a unified permit system. The water rights adjudication process required to transition to the permit system was initiated in 1967 and essentially completed by the late 1980's.

As previously discussed, the 1997 Senate Bill 1 was a comprehensive water management legislative package addressing a wide range of issues including the need to expand statewide water availability modeling capabilities. The TCEQ, its partner agencies, and contractors developed the Texas WAM System during 1997-2003 pursuant to the 1997 Senate Bill 1 to support water rights regulatory and regional and statewide planning activities. Texas WAM System implementation efforts resulted in extensive modifications and many evolving versions of WRAP developed during 1997-2003 and 2005-2021 under contracts between the TCEQ and Texas A&M University System.

Modeling Capabilities Added Since Implementation of WAM System

The Texas Commission on Environmental Quality has continued to improve and expand WRAP since implementation of the WAM System. The U.S. Army Corps of Engineers (USACE) Fort Worth District also cosponsored ongoing efforts at Texas A&M University (TAMU) during 2001-2005 to further expand WRAP under its congressionally authorized Texas Water Allocation Assessment Project. The Texas Water Development Board (TWDB), Brazos River Authority (BRA), Texas Water Resources Institute (TWRI), and TAMU AgriLife Research Service have supported WRAP expansion efforts. The modeling capabilities covered by this *Reference Manual* and accompanying *Users Manual* include many significant improvements and new features added since completion of the initial TCEQ WAM System implementation that have been routinely applied for some time. The following additional major new modeling capabilities have experienced relatively limited practical application to date and are currently being more fully implemented.

Short-term conditional reliability modeling (CRM) provides estimates of the likelihood of meeting diversion, instream flow, hydropower, and storage targets during specified time periods of one month to a year or perhaps several years into the future, given preceding storage levels. CRM uses the same input datasets as conventional WRAP applications. CRM is based on dividing the several-decade-long hydrologic sequences into multiple shorter sequences. *SIM* or *SIMD* repeats the simulation computations with each of the sequences, starting with the same specified initial reservoir storage conditions. *TABLES* determines reliabilities for meeting water right requirements and storage-frequency relationships based on the *SIM* or *SIMD* simulation results. CRM is covered in Chapter 8 of this *Reference Manual*.

Salinity simulation capabilities are covered in the *Salinity Manual* [6]. Natural salt pollution in several major river basins in Texas and neighboring states motivated addition of capabilities for tracking salt concentrations through river/reservoir systems for alternative water management/use scenarios. The WRAP program *SALT* reads water quantity data from a *SIM* or *SIMD* output file along with additional input data regarding salt concentrations and loads of flows entering the river system. The model computes concentrations of the water quality constituents in the regulated stream flows, diversions, and reservoir storage contents throughout the river basin. Options in *TABLES* organize the salinity simulation results.

The original *WRAP* uses a monthly time step. The expanded daily WRAP modeling system composed of the programs *SIMD*, *DAY*, *HEC-DSSVue*, and the daily routines in *TABLES* is described in the *Users* and *Daily Manuals* [2, 5]. *SIMD* input may either include daily naturalized flows employed directly without disaggregating monthly flows or options may be activated for disaggregating monthly flows to daily. The recommended disaggregation option employs daily flow pattern hydrographs. Routing methods model flow translation and attenuation. Routing parameter calibration methods are provided in program *DAY*. Future time steps extending over a forecast period are considered in determining water availability and flood flow capacities. Daily target setting features include high pulse flow environmental requirements. *TABLES* and *HEC-DSSVue* develops frequency relationships and reliability indices reflecting the daily time interval. *SIMD* daily results may also be aggregated to monthly values.

Any number of flood control reservoirs may be operated in *SIMD* either individually or as multiple-reservoir systems to reduce flooding at any number of downstream control points. Operating rules are based on emptying flood control pools expeditiously while assuring that releases do not contribute to flows exceeding specified flood flow limits at downstream control points during a specified future forecast period. Flood frequency analyses of annual peak naturalized flow, regulated flow, and reservoir storage are performed with *TABLES* or *HEC-DSSVue* based on the log-Pearson type III probability distribution.

The primary motivation for developing and applying the daily WRAP modeling system is to expand capabilities for integrating environmental flow standards and their impacts on other water users in water availability modeling. Newer features in *SIMD*, *DAY*, and *TABLES*, including pulse flow features of the daily *SIMD*, improve capabilities for modeling environment flows [5, 27]. As of July 2022, these daily modeling capabilities have been demonstrated through development and application of daily water availability models for the Brazos [44], Trinity [45], Neches [46], and Colorado [47] River Basins.

Organization of the Reference and Users Manuals

This *Reference Manual* describes concepts and methods of the WRAP modeling system exclusive of the specific additional modeling capabilities covered by the *Daily*, *Hydrology*, and *Salinity Manuals*. The *Users Manual* explains the logistics of applying *SIM*, *SIMD*, *TABLES*, and *HEC-DSSVue*. The selected features described in the *Fundamentals Manual* are covered in much greater detail in the *Reference* and *Users Manuals*. The *Programming Manual* documenting the Fortran code for all of the WRAP programs is designed to support software maintenance and improvement but is not necessary in applying the executable programs.

The companion *Reference Manual* and *Users Manual* are designed for different types of use. This *Reference Manual* describes WRAP capabilities and methodologies. The *Reference Manual* introduces the model to the new user and serves as an occasional reference for the experienced user. The *Users Manual* provides the operational logistics required any time anyone is working with WRAP input files. Application of WRAP requires developing and modifying files of input records. The primary purpose of the *Users Manual* is to provide the detailed explanation of file and record content and format required for building and revising input files. The *Users Manual* is organized by computer program with separate chapters for *SIM*, *SIMD*, *TABLES*, and *HEC-DSSVue*. Instructions for employing the programs *HYD*, *DAY*, and *SALT* are provided separately in the *Hydrology*, *Daily*, and *Salinity Manuals*.

Chapters 1, 2, and 9 of this *Reference Manual* provide a general overview of WRAP. Chapter 1 introduces the modeling system and its documentation and describes its origins. Chapter 2 covers the simulation model *SIM* and post-simulation program *TABLES* from a general overview perspective. Chapter 9 discusses aids for detecting and correcting input errors.

Essentially all aspects of WRAP can be categorized as dealing with either natural hydrology or human water resources development, allocation, management, and use (water rights). Hydrology and water right features, respectively, are described in detail in Chapters 3 and 4 of this *Reference Manual*. From a WRAP perspective, hydrology (Chapter 3) consists of natural stream flows at gaged and ungaged sites, reservoir net evaporation minus precipitation depths, and channel losses. Likewise, from a WRAP perspective, water rights (Chapter 4) include constructed infrastructure and institutional arrangements for managing and using the water flowing in rivers and stored in reservoirs. Water rights include storage and conveyance, water supply diversions and return flows, hydroelectric energy generation, environmental instream flow requirements, reservoir/river system operating policies and practices, and water allocation rules and priorities.

Chapter 5 describes *SIM* simulation results. The time series variables computed in the *SIM* simulation are defined. Special *SIM* auxiliary analysis features are outlined in Chapter 6. Capabilities provided by *TABLES* for developing simulation results summaries, water budgets, reliability metrics, frequency tables, and tabulations for transport to *HEC-DSSVue* or other software are explained in Chapter 7.

Short-term conditional reliability modeling (CRM) is covered in Chapter 8 along with five CRM examples based upon the example in the *Fundamentals Manual*.

References cited in this manual by numbers in brackets are listed on pages 359-361. Appendix A on pages 363-368 is a bibliography of WRAP-related publications. Appendix B is a glossary of terms used in the manuals.

Appendix C is a set of very simple examples that illustrate the basic *SIM* and *TABLES* capabilities covered in Chapters 2, 3, and 4 of this *Reference Manual*. Much more realistic examples of applying *SIM*, *SIMD*, *TABLES*, and *HEC-DSSVue* are presented in the *Fundamentals* and *Daily Manuals*. The examples in the *Daily Manual* are extensions of the detailed example introduced in the *Fundamentals Manual*. Input data files for the examples in Appendix C and Chapters 6, 7, and 8 of this *Reference Manual* and in the *Fundamentals*, *Daily*, *Hydrology*, and *Salinity Manuals* are available along with the executable programs and PDFs of the manuals.

CHAPTER 2 OVERVIEW OF THE SIMULATION MODEL

Modeling Capabilities

WRAP is designed for use by water management agencies, consulting firms, and university researchers in the modeling and analysis of river/reservoir system operations. The modeling system may be applied in a wide range of planning and management situations to evaluate alternative water resources development and river regulation strategies. As discussed in the preceding chapter, water availability modeling studies are routinely performed in Texas to support regional and statewide planning activities and the preparation and evaluation of water right permit applications. Model results are used to analyze the capability of a river basin to satisfy specified water use requirements. Basin-wide impacts of changes in water management and use are assessed. Multiple-purpose reservoir system operations may be investigated in operational planning studies for existing facilities and/or feasibility studies for constructing new projects.

WRAP incorporates priority-based water allocation schemes in modeling river regulation and water management. Stream flow and reservoir storage are allocated among water users based on specified priorities. WRAP was motivated by and developed within the framework of the Texas water rights permit system. However, the flexible generalized model is applicable to essentially any water allocation systems and also to situations where water is managed without a structured water rights system. WRAP is applied to river basins that have hundreds of reservoirs, thousands of water supply diversions, complex water use requirements, and complex water management practices. However, it is also applicable to simple systems with one, several, or no reservoirs.

The generalized computer model provides capabilities for simulating a river/reservoir/use system involving essentially any stream tributary configuration. Interbasin transfers of water can be included in the simulation. Closed loops such as conveying water by pipeline from a downstream location to an upstream location on the same stream or from one tributary to another tributary can be modeled. Water management/use may involve reservoir storage, water supply diversions, return flows, environmental instream flow requirements, hydroelectric power generation, and flood control. Multiple-reservoir system operations and off-channel storage may be simulated. Flexibility is provided for modeling the various rules specified in water rights permits and/or other institutional arrangements governing water allocation and management. There are no limits on the number of water rights, control point locations, reservoirs, and other system components included in a model. There is no limit on the number of years included in the hydrologic period-of-analysis.

The monthly *SIM* and daily *SIMD* simulation models are accounting systems for tracking stream flow sequences, subject to reservoir storage capacities and operating rules and water supply diversion, hydroelectric power, and instream flow requirements. Water balance computations are performed in each time step of the simulation. Typically, a simulation will be based on combining (1) a repetition of historical hydrology with (2) a specified scenario of river basin development, water use requirements, and reservoir system operating rules. A broad spectrum of hydrologic and water management scenarios may be simulated. Numerous optional features have been incorporated into the generalized modeling system to address complexities in the variety of ways that people manage and use water. The Fortran programs are designed to facilitate adding new features and options as needs arise.

Water Availability Modeling Process

The conventional water availability modeling process consists of two phases:

1. developing sequences of monthly naturalized stream flows covering the hydrologic period-of-analysis at all pertinent locations
 - a. developing sequences of naturalized flows at stream gaging stations
 - b. extending record lengths and filling in gaps to develop complete sequences at all selected gages covering the specified period-of-analysis
 - c. distributing naturalized flows from gaged to ungaged locations
2. simulating the rights/reservoir/river system, given the input sequences of naturalized flows, to determine regulated and unappropriated flows, storage, reliability indices, flow-frequency relationships and related information regarding water supply capabilities
 - a. simulating the rights/reservoir/river system
 - b. computing water supply reliability and stream flow frequency indices and otherwise organizing/summarizing/displaying simulation results

Naturalized or unregulated stream flows represent historical hydrology without the effects of reservoirs and human water management/use. Naturalized flows at gaging stations are determined by adjusting gaged flows to remove the historical effects of human activities. Various gaging stations in a river basin are installed at different times and have different periods-of-record. Gaps with missing data may occur. Record lengths are extended and missing data reconstituted by regression techniques using data from other gages and other months at the same gage. Naturalized flows at ungaged sites are synthesized based upon the naturalized flows at gaged sites and watershed characteristics.

The WRAP program *HYD* and the Hydrologic Engineering Center's *HEC-DSSVue* include options to assist in adjusting gaged flows to obtain naturalized flows (Task 1a above). Naturalized flows may be distributed from gaged (or known-flow) locations to ungaged (unknown-flow) locations (Task 1c above) within either *HYD* or the *SIM/SIMD* simulation. Naturalized flows have been developed (Tasks 1a and 1b) for the Texas WAM System and are readily available for further application. Watershed parameters for distributing flows (Task 1c) are also incorporated in the Texas WAM System datasets.

A *WRAP-SIM* simulation starts with known naturalized flows provided in the hydrology input file and computes regulated flows and unappropriated flows at all pertinent locations. Regulated and unappropriated flows computed within *SIM* reflect the effects of reservoir storage and water use associated with the water rights included in the input. Regulated flows represent physical flows at a location, some or all of which may be committed to meet water rights requirements. Unappropriated flows are the stream flows remaining after all water rights have received their allocated share of the flow to refill reservoir storage and meet diversion and instream flow requirements. Unappropriated flows represent uncommitted water still available for additional water right permit applicants.

Water is allocated to meet diversion, instream flow, hydroelectric energy, and reservoir storage requirements based on water right priorities. In the Texas WAM System, priorities are based on seniority dates specified in the water right permits. Various other schemes for establishing relative priorities may be adopted as well. Water availability is evaluated in simulation studies from the perspectives of (1) reliabilities in satisfying existing and proposed water use requirements, (2) effects on the reliabilities of other water rights in the river basin, (3) regulated instream flows, and (4) unappropriated flows available for additional water right applicants. Reservoir storage and stream flows are simulated. The WRAP modeling system may be used to evaluate water supply capabilities associated with alternative water resources development projects, water management plans, water use scenarios, demand management strategies, regulatory requirements, and reservoir system operating procedures.

Long-Term Simulation, Iterative Firm Yield, and Short-Term Conditional Reliability Modeling Modes

The WRAP simulation program *SIM* may be applied in the following alternative modes.

1. A single long-term simulation is the default mode.
2. The firm yield analysis option activated by the *FY* record is based on repetitions of the long-term simulation to develop a diversion target (yield) versus reliability table that includes the firm yield if a firm (100% reliability) yield is feasible.
3. The conditional reliability modeling (CRM) option activated by the *CR* record is based on many short-term simulations starting with the same initial storage condition.

In the conventional long-term *SIM* simulation mode, a specified water management and use scenario is combined with naturalized flows and net reservoir evaporation rates covering the entire hydrologic period-of-analysis in a single simulation. The user specifies the storage content of all reservoirs at the beginning of the simulation, defaulting to full to capacity. Optionally, a storage cycling feature described in Chapter 6 is based on repeating the simulation setting beginning-of-simulation storages equal to end-of-simulation storages. Water supply reliability and flow and storage frequency statistics developed by *TABLES* from the *SIM* simulation results represent long-term probabilities or percent-of-time estimates.

SIM has a yield-reliability analysis option described in Chapter 6 that is activated by the *FY* record. The long-term simulation is iteratively repeated multiple times with specified water use targets incremented in each simulation to develop a table of diversion target versus period and volume reliability. The resulting yield-reliability table is written as a *SIM* output file. The table ends with the firm (100% reliability) yield if a firm yield can be obtained.

In the *SIM* conditional reliability modeling (CRM) mode activated by a *CR* record, the long period-of-analysis hydrology is divided into many short sequences defined by options specified by the model-user. The *SIM* simulation is automatically repeated with each hydrologic sequence starting with the same user-specified initial reservoir storage contents. Program *TABLES* develops reliability and frequency relationships from the simulation results. Options are provided in *TABLES* for assigning probabilities to each hydrologic sequence. Water supply reliability and stream flow and storage frequency relationships for periods of a month to several months or a year

into the future are conditioned upon the preceding storage condition. The CRM mode supports short-term operational planning studies and seasonal or real-time reservoir/river system management. CRM is explained in Chapter 8.

Control Point Representation of Spatial Configuration

The spatial configuration of a river/reservoir/water use system is represented in WRAP as a set of control points that represent pertinent sites in the river basin. Figure 2.1 below is a schematic of a river system modeled as a set of 18 control points with reservoirs located at eight of the control points. Reservoirs, diversions, return flows, instream flow requirements, stream flows, evaporation rates, and other system features are assigned control points denoting their locations. Control points provide a mechanism to model spatial connectivity. The *CP* input record for each control point includes the identifier of the next control point located immediately downstream. Various computational routines in the model include algorithms allowing the computations to cascade downstream by control point. Spatial complexity in actual applications may range from a system modeled with a single control point to models with several control points to those with thousands of control points. The number of control points incorporated in the datasets for the river basins in the Texas WAM System listed in Table 1.2 range from 49 to over 3,000.

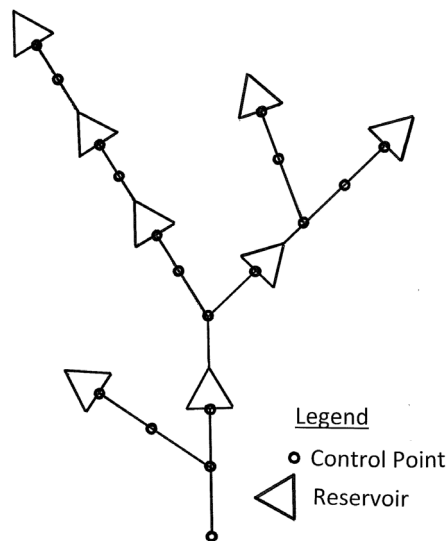


Figure 2.1 Reservoir/River System Schematic

Naturalized stream flows at each control point are either input to *SIM* or computed within the model from flows at other control points. *Primary* control points are sites for which naturalized flows are included in the *SIM* input dataset. The ungaged sites for which flows are computed within *SIM* are called *secondary* control points. Options for distributing naturalized flows from gaged to ungaged control point locations are outlined in Chapter 3. *SIM* computes regulated stream flows, unappropriated stream flows, and other quantities for each control point. The various quantities computed for water rights and reservoirs can also be aggregated by control point location.

Each water right must be assigned a main control point indicating the location at which the right has access to available stream flow. This site is referred to as the control point of the water right though various components of the right such as return flows and multiple reservoirs may be assigned other control point locations. Any number of water rights can be assigned to the same control point. Rights can be grouped such that the rights assigned to a given control point include all those located along specified stream reaches. Multiple water rights at the same control point all have access, in priority order, to the stream flow available at the control point. Any number of reservoirs can be associated with a single control point, but each control point is limited to one set of reservoir net evaporation-precipitation rates. Stream flow depletions and return flows associated with a water right affect stream flows at other control points located downstream.

Simulation Input

Input data for the WRAP programs are provided as records in a set of files as described in the *Users Manual*. The system for organizing the input includes an identifier for each type of record that is placed at the beginning of the records. The *SIM* hydrology input files include sequences of monthly naturalized stream flows (*IN* records) and net reservoir evaporation minus precipitation rates (*EV* records). Naturalized stream flows may be distributed from gaged (known-flow) to ungaged (unknown-flow) control points in either *SIM* or *HYD* using optional alternative methods. Watershed parameters for distributing flows to ungaged water rights sites are provided on *FD*, *FC*, and *WP* records in a flow distribution input file.

Input describing water rights includes control point location, annual diversion amount, instream flow requirements, hydroelectric energy demand, storage capacity, type of water use, return flow, and priority specifications. A set of 12 monthly water use distribution factors may be input for each water use type. Diversion, instream flow, and hydropower targets optionally may be specified as a function of reservoir storage or stream flow. Return flows may be specified as a fraction of diversions or as a constant amount, return flow location, and whether the return flows occur the same month as the diversion or the next month.

Water right priority numbers may be entered for each individual right on *WR* or *IF* records or for water use type groups on *UP* records. Optionally, water use demands may be met in upstream-to-downstream order. Priority numbers may reflect priority dates specified in the permit for each right. For example, a water right established as of May 1, 1972 is represented by a priority number of 19720501, which is a smaller number than the priority of more junior rights. The model-user can adopt other schemes for assigning relative priorities to fit the particular application. The model provides considerable flexibility for applying ingenuity in combining water right modeling options to simulate a particular water management/use scenario.

Reservoirs are described by elevation versus storage volume and surface area relationships, storage capacity allocations, and multiple-reservoir release rules for any reservoirs operated as a system. Storage-area relationships may be input in either tabular form or as coefficients for an equation. Multiple-reservoir system operations are based on balancing the percentage full of specified zones in each reservoir included in the system for a particular right. Although reservoirs on rivers and off-channel reservoirs are treated basically the same, certain modeling features are more relevant to each of these two types of reservoirs.

Simulation Results

The voluminous output for each month of a *WRAP-SIM* simulation includes:

- naturalized, regulated, and unappropriated flows for each control point
- return flows from diversions that are returned at each control point
- channel losses and loss credits for the stream reach below each control point
- diversions, diversion shortages, and return flows for each water right
- hydroelectric energy generated and energy shortages
- instream flow targets and shortages
- storage and net evaporation-precipitation for each reservoir, right, and control point
- amount of water available and stream flow depletions for each right

Simulation results are written to a *SIM* output file, which is read by *TABLES*. The program *TABLES* computes reliability indices, including volume and period reliabilities, and stream flow and storage frequency relationships and organizes the simulation results as tables of information in various user-specified optional formats. *SIM* results can be easily plotted with HEC-DSSVue.

Table 2.1
Variables in the WRAP-SIM Output File

<i>WR</i> Record Rights	Instream Flow Rights	Control Points	Reservoir/Hydropower
diversion or energy target	instream flow target	diversion target	energy generated
diversion/energy shortage	flow shortage	diversion shortage	energy shortage
storage volume	storage volume	storage volume	secondary energy
evap-precip volume	evap-precip volume	evap-precip volume	storage contents volume
available stream flow	available stream flow	unappropriated flow	storage capacity volume
stream flow depletion	stream flow depletion	stream flow depletion	evap-precip volume
reservoir releases	required res release	naturalized flow	evap-precip depth
return flow	reservoir release	regulated flow	adjusted evap-prec depth
available flow increase	reservoir release shortage	reservoir releases	reservoir inflow
water right identifier	flow switch volume	return flow	reservoir release
first group identifier	flow switch count	channel loss	turbine flow
second group identifier	water right identifier	channel loss credit	water surface elevation
		instream flow target	reservoir identifier

For each month of a *SIM* simulation, output records are written for user-selected water rights (*WR* record rights and instream flow *IF* rights), control points, and reservoir/hydropower projects. These records contain the data listed in Tables 2.1 and 5.1. Some data are unique to water right, control point, or reservoir/hydropower output records. For example, naturalized, regulated, and unappropriated flows, and channel losses are associated only with control points. Other data are repeated on two or three of the record types. For example, reservoir storage and evaporation are written to all three records. If one water right with one reservoir is located at a control point, reservoir storage will be identical on all three records. However, the control point records contain the summation of storage contents of all reservoirs assigned to the control point. Likewise, multiple water rights may be assigned to the same reservoir. Diversions and shortages on a control point record are the totals for all the rights assigned to the control point. The diversions and shortages on a water right output record are associated with a single *WR* input record.

As discussed in Chapter 7, the time series of monthly values of the variables listed in Table 2.1 are read by the post-simulation program *TABLES*, which creates user-specified tables to organize, display, and summarize simulation results. Some *TABLES* routines simply rearrange and tabulate, with appropriate table headings, selected data read from *SIM* input or output files. Other routines include computational algorithms, which may range from simple sums or statistics to more complex arithmetic operations. A reliability table for water supply diversion or hydroelectric energy targets includes volume and period reliabilities for supplying various percentages of the target demands. Frequency tables are developed for naturalized, regulated, and unappropriated flows, reservoir storage, and instream flow shortages. Reservoir storage also may be displayed as comparative tables of percentages of capacity and drawdown-duration tables. *TABLES* also creates tables organizing and summarizing water rights data read from a *SIM* input file.

Simulation results can also be stored by *SIM* and/or *TABLES* in as DSS records in DSS files. HEC-DSSVue provides comprehensive capabilities for managing time series datasets, plotting graphs, mathematical operations, and statistical analyses.

Units of Measure

Any units may be adopted. However, the set of all input data units and conversion factors must be computationally consistent. The various flows (volume per month or volume per year) must have the same volume units as the reservoir storage volume. Most of the input data are volumes, areas, or depths, including annual and monthly diversion volumes, volume/month stream flow rates, reservoir storage volume and surface area, and net evaporation-precipitation depths. Net evaporation volumes are depths multiplied by reservoir water surface areas. An example of a set of computationally consistent (feet \times acre = acre-feet) English units is as follows:

- acre-feet for storage volume and volume/month or volume/year quantities
- acres for reservoir surface area
- feet for monthly net reservoir surface evaporation-precipitation rates

A set of computationally consistent (meters \times km² = million m³) metric units is as follows:

- million cubic meters for the reservoir storage and volume/month or volume/year quantities
- square kilometers for reservoir surface area
- meters for monthly net reservoir surface evaporation-precipitation rates

For many WRAP applications, all input is entered in consistent units without needing conversions within the model. However, as described in the *Users Manual*, several input variables are multipliers that may be used as unit conversions. Most of these unit conversion factors are entered on the *SIM* or *HYD* multiplier factor *XL* record described in the *Users Manual*. Computations within *TABLES* do not depend on units, but an option allows the user to specify units to be written in the table headings.

The hydroelectric power factor entered on the *SIM* multiplier factor *XL* record entails unit conversions and specific weight and is described later in the hydropower section of Chapter 4. A multiplier factor entered on the *XL* record associated with the curve number method for distributing flows from gaged to ungaged control points is defined in Chapter 3.

Organization of the Simulation Computations

The river/reservoir system simulation model *SIM*, post-simulation program *TABLES*, and user interface *WinWRAP* are documented by this *Reference Manual* and accompanying *Users Manual*. Instructions for preparing input files are provided in the *Users Manual (UM)*. Modeling concepts and methods are explained in the chapters and appendices of the *Reference Manual (RM)* noted in Table 2.2. The basics of *SIM* and *TABLES* are also described in the *Fundamentals Manual*. *WinWRAP* is described in detail in the *Fundamentals Manual*. The *Programming Manual* is designed for individuals interested in examining or modifying the Fortran code but is not needed for applying the executable programs.

Table 2.2
Organization of *SIM* and *TABLES* Documentation

WRAP Program	<i>SIM</i>	<i>TABLES</i>
Explanation of model capabilities and methods	RM Ch 2-6,8,9	RM Ch 2,7,8
Detailed instructions for preparing input data	UM Ch 2 and 3	UM Chap 4
Example datasets	RM Appd C and Fundamentals Manual	RM Appd C
Information regarding Fortran programs	Programming Manual	

WRAP-SIM Simulation Overview

The *SIM* simulation model allocates water to meet requirements specified in the water rights input for each sequential month of naturalized stream flows and net evaporation-precipitation rates provided in the hydrology input files. Water supply diversion, instream flow, and hydroelectric power generation requirements are met, and reservoir storage is filled, to the extent allowed by the water remaining in storage from the previous month, diversion return flows from the previous month, and stream inflows during the current month. Water supply diversion, instream flow, and/or hydroelectric energy shortages are declared whenever insufficient stream flow and/or storage are available to fully satisfy the target demands.

The *SIM* simulation procedure is outlined in Figure 2.2 from a general overview perspective. After first reading a major portion of the input data, the simulation is performed in a set of nested loops. The computations proceed by year and, within each year, by month. Within each month, the water rights are considered in priority order, and the computations are performed for each water right in turn. Water right output data records described in the *Users Manual* are written to the *SIM* output file as each right is considered in the water rights priority loop. Control point output is written at the completion of the water rights loop.

For each month of the simulation, *SIM* performs the water accounting computations for each water right, in turn, on a priority basis. The computations proceed by month and, within each month, by water right with the most senior water right in the basin being considered first. Water allocation computations are performed for each water right in priority order.

-
1. Program *HYD* facilitates developing the *WRAP-SIM* hydrology input files.
 2. The *SIM* simulation is outlined as follows.
 - Input data are read and organized.
 - DAT file record counts are performed and array dimensions are set.
 - Pertinent optional files are selected and activated.
 - All input except that related to hydrology is read.
 - *IN* and *EV* records may be read depending on *INEV* on *JO* record.
 - Various data manipulations are performed.
 - Water rights are ranked in priority order.
 - Watershed parameters are read and manipulated for flow distribution.
 - Yield-reliability analysis (*FY* record), BES options (*JO* record), and dual simulation options (*PX* record) involve iterative repetition of the simulation.
 - Annual Loop (repeated for each year of simulation)
 - *IN* and *EV* records are read or previously read array is accessed.
 - Flows are distributed from gaged to ungaged sites.
 - Incremental negative inflow adjustments are developed.
 - Flows for January are adjusted for return flows from prior December.
 - Monthly Loop (repeated for each month of simulation)
 - Net evaporation-precipitation adjustment option. *
 - Spills associated with monthly varying storage capacity option. *
 - Flow adjustments for constant inflow/outflow option. *
 - Water Right Loop (repeated for each right in priority order)
 - + (First and second pass through loop for instream flow options) + *
 - + 1. The diversion, instream flow, or hydropower target is set. + *
 - + 2. The amount of water available to right is determined. + *
 - + Unappropriated flows are checked. + *
 - + Regulated flows are checked. + *
 - + (Channel losses are considered in checking flows.) + *
 - + 3. Diversions, reservoir releases, and return flows are made. + *
 - + (Includes reservoir water balance with iterative net + *
 - + evaporation-precipitation and hydropower computations.) + *
 - + 4. Available stream flow at all control points is adjusted. + *
 - + (Channel losses are considered in adjusting available flows.) + *
 - + 5. Water right output records are developed and written. + *
 - ++++++ ++++++ ++++++ ++++++ ++++++ ++++++ ++++++ ++++++ ++++++ ++++++ *
 - Control point and reservoir output records are developed and written. *
 - *****

Results stored in memory are recorded in DSS and SOU files at completion of simulation.

 3. The post-simulation program *TABLES* is used to compute reliability and frequency metrics and organize, summarize, and display the *SIM* simulation results in user-specified formats.

Figure 2.2 Outline of WRAP Program *SIM* Simulation

As *SIM* considers each water right, pertinent computational algorithms are activated to make water management decisions and perform volume balance accounting computations. Diversions and diversion shortages are computed. Environmental instream flow requirements are considered. Reservoir storage capacity is filled to the extent allowed by available stream flow. Reservoir net evaporation-precipitation volume is computed and incorporated in the water balance. Return flows are computed and re-enter the stream at user-specified control points. An accounting is maintained of storage levels in each reservoir and stream flow still available at each control point.

Considerable flexibility is provided for specifying water right requirements. The following features of the computational algorithms are fundamental to representing water rights requirements in the monthly time step *SIM* model. As discussed in the *Daily Manual*, *SIMD* also has flow forecasting and routing routines connecting time steps.

- The simulation progresses sequentially by month. The following model features connect a month with the preceding month. The computed end-of-period reservoir storage for a month becomes the given beginning-of-period storage for the next month. An option allows return flows from diversions in a given month to be returned to the stream the next month. Hydropower releases may also be made available at downstream locations optionally the following month. Targets may be set based on cumulative flows. Options limit cumulative annual or seasonal diversions, withdrawals from storage, and stream flow depletions.
- A water rights priority loop is embedded within the monthly computational loop. In a particular month, the water rights are considered in priority order. Thus, in general, each water right is affected only by more senior rights, with the following exceptions. Reservoir storage is affected by computations for previous months. Next-month return flow options allow senior rights access to junior return flows. Instream flow requirements may be considered in an optional dual loop within the water rights loop, allowing junior rights to affect regulated flow constraints on water availability for more senior rights.

Steps in the WRAP-SIM Simulation

All input data is read at the beginning of a *SIM* execution, except naturalized flows and net evaporation rates and the optional flow adjustment file that are read during each year of the simulation. Various manipulations of the water rights input data read at the beginning are performed prior to starting the monthly simulation. This includes a ranking mechanism for identifying the priority order of the water rights based on priority specifications from the input data.

The annual loop begins with reading the stream flow and evaporation data for each of the 12 months of that year and distributing flows from gaged to ungaged control points. The computations are then performed on a monthly basis. The data in the control point and reservoir/hydropower output records listed in Table 2.1 reflect the effects of all the rights and are outputted each month at the completion of the water rights loop.

The simulation proceeds by month and, within each month, by water right in priority order with the most senior right in the basin being considered first. Thus, if supplies are insufficient to meet all demands in a given month, the water available to a particular water right is not adversely affected by other rights that are more junior in priority. Most of the system simulation computations

are performed within the water rights priority loop. For each individual water right in turn, the computations are performed in four stages.

1. The diversion, instream flow, or hydropower generation target is set based on specifications read from water right *WR*, instream flow *IF*, water use coefficient *UC*, supplemental options *SO*, target options *TO*, flow switch *FS*, time series *TS*, and drought index *DI/IS/IP* records.
2. The amount of stream flow available to the right is determined. Stream flow availability is determined as the lesser of the stream flow availability array amounts at the control point of the water right and at each of the control points located downstream.
3. Water volume balance computations are performed to compute the stream flow depletion, net reservoir evaporation, end-of-period storage, return flow, diversion and diversion shortage, and hydroelectric energy generated and shortage. The interrelationships between the variables necessitate an iterative algorithm. For multiple reservoir system operations, the releases and storages for all the system reservoirs are computed.
4. The stream flow availability array values at the control point of the water right and at downstream control points are decreased by a stream flow depletion and increased by a return flow or hydropower release, with adjustments for channel losses or loss credits. Upon completion of the water rights computation loop, regulated and unappropriated flows are determined from the stream flow availability array as adjusted for the effects of the water rights.

Figure 2.2 and the present discussion outline a single simulation. Various options discussed later in this manual involve two or more repetitions of the simulation. As explained in Chapter 4, instream flow options may activate a second pass through the water rights loop in a particular month. Multiple repetitions of the entire simulation may be performed automatically within *SIM* for purposes of using stream flow depletions determined in an initial simulation as an upper limit constraining depletions in a subsequent simulation (Chapter 4), developing yield-reliability relationships (Chapter 6), or setting beginning storage equal to ending storage (Chapter 6).

Example 1 - Stages Repeated for Each Right Within Water Rights Priority Loop

Example 1 illustrates the basic computational stages within the water rights loop. Data for the example are presented in Figure 2.3 and Tables 2.3, 2.4, and 2.5. The example focuses on the computations for just one month of a simulation. The spatial configuration of the system is represented by five control points shown in Figure 2.3. Information for each of three water rights is provided in Table 2.3. Water right WR-A includes reservoir storage as well as a diversion. Water rights WR-B and WR-C are run-of-river diversion rights.

A *SIM* simulation consists of allocating available water to water rights in priority order. Available water consists of stream flow during the month and reservoir storage content at the beginning of the month. For this particular month, naturalized stream flow is 100 acre-feet at control point CP5 with lesser amounts at the four other control points located upstream of CP5 as tabulated in column 2 of Table 2.5. The beginning-of-month storage in the WR-A reservoir at CP4 is 195 ac-ft as shown in column 6 of Table 2.3. These naturalized flows and beginning-of-month storage are to be allocated to meet the three diversion requirements, satisfy reservoir net precipitation-evaporation, and refill the reservoir storage to capacity. The water use requirements

are met to the extent allowed by available stream flows and beginning-of-month reservoir storage. The water rights are listed in priority order in Table 2.3 with their priorities being tabulated in column 3. The computations begin with WR-A, the most senior right. Water rights WR-B and WR-C are then considered in order of priority.

Stage 1 of the water right computations consists of determining the diversion target, which in general may require various computations. For this simple example, the diversion targets are given in the fourth column of Table 2.3. WR-A has a target of 15 acre-feet/month.

Table 2.3
Water Rights Information for Example 1

1	2	3	4	5	6
Water Right Identifier	Control Point	Priority Number	Target Diversion (ac-ft/mon)	Reservoir Capacity (acre-feet)	Initial Storage (acre-feet)
WR-A	CP-4	1954	15	200	195
WR-B	CP-1	1972	10	-	-
WR-C	CP-2	1999	40	-	-

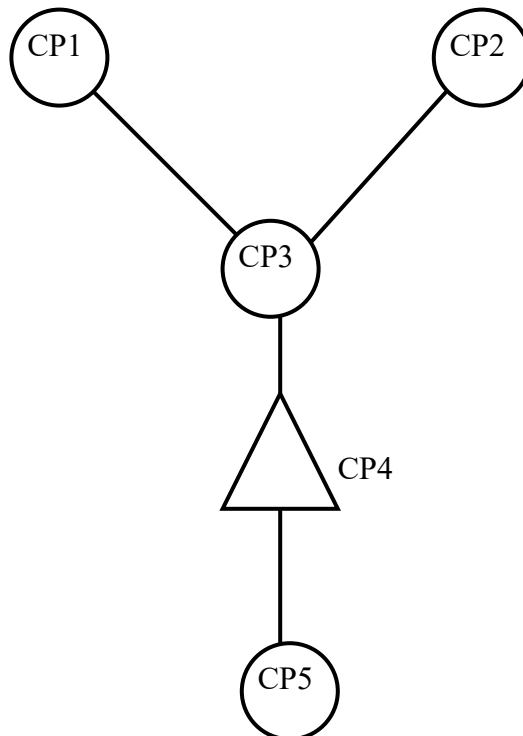


Figure 2.3 Control Point Schematic for Example 1

Stage 2 consists of determining the amount of water available this month for water right WR-A at control point CP4. The amount of stream flow available is the lesser of the naturalized

flow at CP4 (80 acre-feet) and all downstream control points (100 acre-feet at CP5). Thus, for WR-A, the available stream flow this month is 80 acre-feet as shown in column 3 of Table 2.4. Beginning-of-month storage of 195 acre-feet is also available.

Table 2.4
Water Rights Simulation Results for Example 1

1	2	3	4	5	6	7	8	9
Water Right Identifier	Control Point	Available Streamflow (acre-feet)	Reservoir Evap- Prec (acre-feet)	End Month Storage (acre-feet)	Target Diversion (acre-feet)	Actual Diversion (acre-feet)	Diversion Shortage (acre-feet)	Streamflow Depletion (acre-feet)
WR-A	CP-4	80	20	200	15	15	-0-	40
WR-B	CP-1	20	-	-	10	10	-0-	10
WR-C	CP-2	30	-	-	40	30	10	30

Table 2.5
Stream Flow for the Month at Each Control Point in Example 1

1	2	3	4	5	6	7	8
Control Point Identifier	Naturalized Flow (acre-feet)	<u>After WR-A</u> CP Flow (acre-feet)	Available Flow (acre-feet)	<u>After WR-B</u> CP Flow (acre-feet)	Available Flow (acre-feet)	<u>After WR-C</u> Regulated Flow (acre-feet)	Unappropriated Flow (acre-feet)
CP-1	20	20	20	10	10	10	0
CP-2	45	45	40	45	30	15	0
CP-3	70	70	40	60	30	30	0
CP-4	80	40	40	30	30	0	0
CP-5	100	60	60	50	50	20	20

Stage 3 for right WR-A consists of performing water budget computations to determine the extent to which the 15 acre-feet diversion target for this month will be met. The beginning-of-month reservoir storage of 195 ac-ft is 5 ac-ft below the storage capacity of 200 ac-ft. As discussed later, the volume of reservoir net evaporation-precipitation is computed by averaging the water surface area at the beginning and end of the month, determined as a function of storage, and multiplying by a net evaporation-precipitation depth provided in the input data. An iterative algorithm is required to compute the net evaporation-precipitation volume and end-of-month storage since these two variables are both dependent on each other. For purposes of this example, if the reservoir is full at the end of the month, we will assume that computations, not shown, yield a net evaporation-precipitation volume of 20 ac-ft. Thus, requirements for water right WR-A are 20 ac-ft for net evaporation-precipitation (based on the reservoir being completely refilled), 5 ac-ft for refilling storage, and 15 ac-ft for the water supply diversion, for a total of 40 ac-ft. These requirements are all met by the available stream flow of 80 ac-ft.

Stage 4 consists of adjusting the stream flows at CP4 and CP5 to reflect the stream flow depletion of 40 ac-ft at CP4. Prior to considering WR-A, the available (yet unappropriated) stream

flows at CP4 and CP5 are the naturalized flows of 80 and 100 ac-ft. Reducing the flows at CP4 and CP5 by the WR-A stream flow depletion of 40 ac-ft results in the water availability array values of control point (CP) flows shown in column 3 of Table 2.5. The now available (still unappropriated) stream flows at each control point are tabulated in column 4 of Table 2.5.

Water right WR-B at CP1 is next in the water rights loop. Stage 1 consists of setting the run-of-river diversion requirement of 10 ac-ft from Table 2.3. Stage 2 consists of determining the amount of stream flow available to WR-B as the lesser of the CP flows at CP-1 (20 ac-ft) and the downstream CP3 (70 ac-ft), CP4 (40 ac-ft), and CP5 (60 ac-ft). Thus, 20 ac-ft is available for WR-B. Stage 3 consists of allocating water to satisfy the 10 ac-ft diversion target. Stage 4 consists of adjusting flows at CP1 and all downstream control points to reflect the WR-B stream flow depletion of 10 ac-ft at CP1.

Water right WR-C at CP2 is next in the water rights loop. Stage 1 consists of setting the run-of-river diversion target of 40 ac-ft. Stage 2 consists of determining the amount of stream flow available to WR-C as the lesser of the CP flows at CP2 (45 ac-ft) and the downstream CP3 (60 ac-ft), CP4 (30 ac-ft), and CP5 (50 ac-ft). Thus, 30 ac-ft is available for WR-C. Stage 3 consists of allocating water to meet the run-of-river diversion requirement of 40 ac-ft. The actual diversion is limited to the available stream flow of 30 ac-ft, and a shortage of 10 ac-ft is declared. Stage 4 consists of adjusting flows at CP1 and all downstream control points to reflect the WR-B stream flow depletion of 30 ac-ft at CP2.

The computed water right diversions, shortage, and end-of-month storage are tabulated in Table 2.4. The final regulated flows and unappropriated flows at each control point are shown in columns 7 and 8 of Table 2.5.

Water Accounting Procedures

Thus, as illustrated by the preceding example, for a given month, as the computations are performed for each water right in priority order, an accounting is maintained of the amount of regulated and unappropriated flow remaining at each control point location. Stream flow is treated as total flows rather than incremental or local flows. An intermediate computational water availability array of stream flows at each control point begins as the naturalized flow and is adjusted to reflect the effects of each water right located at the control point or upstream. As each water right is considered in priority order, the amount of stream flow available to the right is determined as the minimum of this flow at each of the individual downstream control points and the control point of the water right. After the stream flow depletion, return flow, and other variable values are determined for a water right, the water availability array values for that control point and each downstream control point are adjusted appropriately. Flows are decreased by depletions made to fill reservoir storage and meet diversion requirements. Flows are increased by return flows, hydropower releases, and reservoir releases. Channel losses may be included in the computations.

The stream flow depletion for a water right with reservoir storage will include the net volume of evaporation less precipitation. The stream flow depletion may also include water taken to refill previously drawn-down reservoir storage. Conversely, water use requirements may be met by withdrawals from reservoir storage. The water accounting computations for a storage right include computation of reservoir net evaporation-precipitation volume. An input net evaporation

minus precipitation depth is applied to the average water surface area, which is determined as a function of average storage during the period, determined by averaging the storage at the beginning and end of the period. An iterative algorithm is used since evaporation volume depends on end-of-period storage, which is a function of evaporation. Likewise, an iterative algorithm is used to determine hydroelectric power releases, which depend on head, which is a function of end-of-month storage.

The end-of-period reservoir storage content for a particular period becomes the beginning storage content for the next period in the period computation loop. The end-of-period reservoir storage content S_T is computed in the model based on the water volume balance equation:

$$S_{T-1} + D_{SF} = W_{WS} + R + E + S_T \quad (2.1)$$

where:

- S_{T-1} - reservoir storage content at the end of the previous time period T-1
- S_T - reservoir storage content at the end of the current time period T
- D_{SF} - stream flow depletion during the time period T
- W_{WS} - water supply withdrawal or diversion from the reservoir during period T
- R - release for hydropower, instream flow, or other downstream requirements
- E - net reservoir surface evaporation less precipitation during time period T

The term *stream flow depletion* (D_{SF}) refers to the amount of stream flow appropriated by a water right to meet water use requirements and refill reservoir storage, while accounting for net evaporation-precipitation. *SIM* works with total flows, rather than incremental flows, at each control point. Stream flow depletions represent the water taken by the right from available stream flow. The effects of senior rights as well as naturalized flows are incorporated in the available stream flow. Reservoir spills are also reflected in the available stream flow, though not actually computed except for releases resulting from lowering the pool level for the seasonal rule curve option. Determination of net evaporation volumes and hydropower releases necessitate an iterative algorithm with the water balance computations being repeated until a stop criterion is met.

Any number of water rights may include storage capacity in the same reservoir. Each right allows storage to be refilled to a specified cumulative storage capacity with a specified priority. The storage capacity associated with refilling by junior rights must equal or exceed refill capacities associated with more senior rights. All rights associated with a reservoir have access to all water in their active pools for use in meeting diversion, instream flow, and hydropower requirements. An inactive pool capacity may also be specified for each right, from which the right can not take water. An option associated with the evaporation allocation *EA* record is described in Chapter 4 that allows a reservoir with multiple owners to be modeled as multiple water rights and multiple reservoirs.

End-of-period storage depends upon all the rights associated with the reservoir. For a senior water right, the beginning-of-period storage can be impacted by the computations for the previous month for junior rights at the same reservoir. For a hydropower right, the actual beginning-of-period and end-of-period storages are used in the computations, even if the capacity associated with the right is exceeded due to other rights. For a diversion right, the beginning-of-period and end-of-period storages used in the computations for that particular right are limited to not exceed the storage capacity associated with the right. Thus, the storage capacity for a junior right at a reservoir must be equal to or greater than the storage capacity of any senior right at the reservoir.

Constructing a Model with WRAP

Building a WRAP model for a particular river basin consists of developing input information in the format of records that are stored in files. Required input files must be developed prior to running the programs. Model-users create and revise various input files in the format outlined in the *Users Manual* using their choice of editor, spreadsheet program, and/or other software. Microsoft Excel, Word, WordPad, and Notepad are popular programs that may be used to create, edit, and manipulate text files used in WRAP. These Microsoft programs may be accessed directly from *WinWRAP*. Certain other input files are created by the WRAP programs. *HYD* output files become *SIM* input files, and *SIM* output files become *TABLES* input files.

The *Users Manual* describes the data to be entered in each field of each type of record. Each *HYD* and *SIM* input record begins with a two-character identifier. *TABLES* input records begin with a four-character identifier. The manuals cite record types by these identifiers. The record types and associated identifiers provide a mechanism for organizing and labeling the input data. For example, a control point *CP* record is required for each control point to store certain information. In WRAP, a water right is defined as the information provided on a water right *WR* record or instream flow *IF* record and other supporting records associated with the *WR* or *IF* record. In terms of number of records, the majority of the *SIM* input for a typical application usually consists of the naturalized stream flows stored on inflow *IN* records and net evaporation-precipitation rates on evaporation *EV* records. Many types of records are described in the *Users Manual*. Most are optional. Switches for activating options as well as input describing the system being modeled are entered in the various fields of the different types of records.

The size of a *SIM* input dataset may vary from a few records to many thousands of records. The smallest possible *SIM* model would contain one each of the *JD*, *CP*, *WR*, *IN*, and *ED* records described in the *Users Manual*. Actual applications may involve datasets with less than a hundred records, but many typical applications involve several thousand records. A *SIM* model with 500 control points, a 50-year period-of-analysis, naturalized stream flows at 20 gaged control points, and evaporation-precipitation rates at 20 control points includes: 500 *CP* records; 1,000 *IN* records (50 for each of 20 control points); 1,000 *EV* records; 480 *FD* and *WP* records for distributing flows from 20 gaged to 480 ungaged control points; and many hundreds of water rights *WR* records and other records of various types.

WRAP applications may be simple. A *SIM* input dataset may involve only a few types of records using relatively simple options. On the other hand, applications may be quite complex. River basin hydrology, water control facilities, water use requirements, institutional water allocation procedures, and management policies/practices for major river basins are complicated. Many varied options are incorporated in the generalized WRAP modeling system in order to provide flexible capabilities for analyzing a comprehensive range of river basin management situations. Complexities in applying WRAP are related primarily to (1) the numerous optional features available for modeling various complexities of water management and (2) the need to compile and manage large amounts of data. Ingenuity is required to combine the appropriate WRAP options to model complex systems of rivers, reservoirs, and water rights. Significant time, effort, and expertise may be required to compile the voluminous input data, perform a simulation study, and analyze and interpret results.

Understanding WRAP requires carefully studying the *Reference* and *Users Manuals* as well as gaining experience in actually applying the model. Even for experienced users, the *Users Manual* must be referenced frequently in developing and modifying input data. Input files for Example 2 below and the examples presented in Appendices B and C and the *Fundamentals Manual* are distributed with the programs. An effective aid in becoming familiar with the model is to experiment with the examples by modifying them to include various features of interest, rerunning, and examining the results. Comparison of model results with a few selected pencil/calculator computations provides a good way to confirm your understanding of particular computational algorithms in the model. All of the computations in WRAP are trackable. In applying particular aspects of the model, experimenting with a simple data set with easy-to-track numbers is often worthwhile prior to tackling the complex real world river basin modeling problem.

The following Example 2 is a simple hypothetical application presented to introduce basic features of *SIM* and *TABLES*. The example combines title *T1*, *T2*, comment **, job control data *JD*, use coefficient *UC*, control point *CP*, instream flow *IF*, water right *WR*, water right reservoir storage *WS*, storage volume *SV* versus surface area *SA*, end of data *ED*, inflow *IN*, and evaporation *EV* records, all stored in a DAT file with the filename Exam1.dat. This represents only 13 of the 54 *SIM* input record types outlined in the *Users Manual*, and many of the fields of these records remain blank, meaning various optional features are not used. However, the fundamental record types introduced by this simple example may be the only records needed to construct real-world models.

A large river basin with many pertinent sites simply means more *CP* records. The models for the larger river basins in the Texas WAM System have thousands of control points. A greater number of reservoirs and water rights translate to more *IF*, *WR*, *WS*, *SV*, and *SA* records. A several decade long hydrologic period-of-analysis requires many more *IN* and *EV* records. As the complexity of the river basin management system increases and/or various other modeling situations are encountered, the various optional features described in subsequent chapters are incorporated into the modeling application. Most water management situations may be modeled using simple basic features of WRAP. However, optional capabilities are provided to model a comprehensive range of complicated water rights and water management scenarios.

Example 2: A Simple WRAP-SIM Model Illustrating Basic Modeling Features

A system consisting of a reservoir, two water supply diversions, and an environmental instream flow requirement, is modeled using a 36 month 2016-2018 hydrologic period-of-analysis. The *WRAP-SIM* input file (filename Exam2.DAT) and the first part of the output file (Exam2.OUT) are reproduced as Tables 2.6 and 2.8. To save space, only the first twelve months of the simulation results are included in Table 2.8. *TABLES* input and output files (filenames Tab2.TIN and Tab2.TOU) are shown in Tables 2.7 and 2.9. Information entered in each field of each *SIM* and *TABLES* input record is explained in the *SIM* and *TABLES* chapters, respectively of the *Users Manual*. The data in the *SIM* output file are defined in Tables 5.1 through 5.5 of Chapter 5. Several tables created by *TABLES* (filename Tab2.TOU) from the *SIM* output file (Exam2.OUT) summarizing the simulation results are shown in Table 2.9.

As shown in Figure 2.4, the spatial configuration is represented by two control points, with identifiers CP1 and CP2. Information describing this system is contained in the *SIM* input file with filename Exam2.DAT reproduced as Table 2.6.

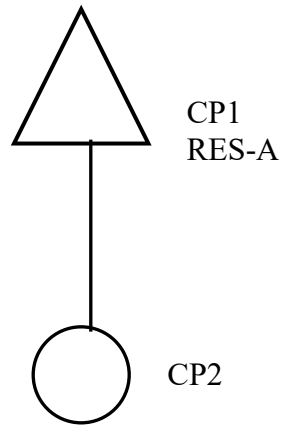


Figure 2.4 Control Point Schematic for Example 2

Of the three water rights, the environmental instream flow requirement of 1,000 acre-feet/month at control point CP2 has the highest priority (priority number 1). The 38,000 acre-feet/year run-of-river irrigation diversion right at CP2 is the most junior (priority number 3). The third right consists of a municipal diversion of 96,000 ac-ft/year from RES-A and refilling the storage capacity of 110,000 acre-feet. Annual instream flow and diversion requirements are distributed over the 12 months of the year using use coefficients entered on *UC* records that are connected to *WR* and *IF* records by use identifiers. The default is a constant uniform distribution.

The next-month return flow option is adopted for the right with identifier Municipal Right. A return flow of 40 percent of the diversion occurring at control point CP1 is returned at CP2 in the next month following the diversion. Return flows are incorporated in the available stream flows at control point CP2 at the beginning of the priority sequence in the next month of the simulation.

The naturalized stream flows on the *IN* records are in units of acre-feet/month. The net evaporation-precipitation rates on the *EV* records are in inches. A multiplier factor of 0.08333 is included on the *CP* record to convert the evaporation-precipitation depths to feet. A storage (acre-feet) versus water surface area (acres) relationship for reservoir Res-A is defined by *SV/SA* records.

The system is simulated with *SIM*, and the simulation results are organized using program *TABLES*. The *TABLES* input file (filename Exam2.TIN) shown in Table 2.7 and *SIM* output file (Exam2.OUT) shown partially in Table 2.8 are read by *TABLES* to create file Exam2.OUT, which is reproduced as Table 2.9. The tables shown in Table 2.9 illustrate some of the types and variations of tables that may be created by *TABLES* to organize, summarize, and analyze simulation results.

Table 2.6
SIM Input File for Example 2

```

T1 Example 2 - WRAP-SIM Input File Exam2.DAT
T2 Example 2 from Chapter 2 of the Reference Manual
**      1      2      3      4      5      6      7      8      9      10     11
**3456789012345678901234567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !      !      !      !
JD      3      2016      1      -1      -1
JO      3
**
UC munic 0.06  0.06  0.07  0.07  0.08  0.10  0.13  0.12  0.09  0.08  0.08  0.06
UC irrig 0.00  0.00  0.04  0.12  0.19  0.22  0.22  0.15  0.05  0.01  0.00  0.00
**
CP  CP1  CP2      0.08333
CP  CP2  OUT
**
IF  CP2  12000      1      Instream Flow
WR  CP2  38000  irrig  3      Irrigation Right
WR  CP1  96000  munic  2      2      0.4      Municipal Right
WS Res-A 110000
**
SV Res-A  0  1030  3730  10800  27700  53400  92100  112000
SA      0  140  409  1150  2210  3100  4690  6160
ED
IN  CP1  2016  10200  6540  3710  7350  15100  904  112  328  972  2650  17300  1290
IN  CP2  2016  12700  7660  4760  9190  21400  1130  145  447  1220  3310  21800  1620
EV  CP1  2016  3.7  3.9  3.9  3.8  4.2  4.5  4.6  4.3  4.1  3.9  4  3.9
**
IN  CP1  2017  3390  3110  12900  42300  62700  76500  16900  21200  25700  8810  1560  1850
IN  CP2  2017  4160  3780  15800  51600  78000  96800  21200  26500  31400  11900  1930  2310
EV  CP1  2017  3.6  3.7  3.8  3.6  4.1  4.3  4.4  4.2  4  3.7  3.9  3.7
**
IN  CP1  2018  3290  8970  1570  2410  48900  5630  7990  3910  1090  1740  13700  14600
IN  CP2  2018  4090  11200  2140  3210  59300  7160  10060  4950  1380  2320  17100  18300
EV  CP1  2018  3.8  3.9  4.0  3.8  4.1  4.2  4.3  4.4  4.2  3.7  4.1  3.7

```

Table 2.7
TABLES Input File for Example 2

```

COMM Example 2 - TABLES Input File Exam2.TIN
**      1      2      3      4      5
** 5678901234567890123456789012345678901234567890123456
**      !      !      !      !      !      !      !      !      !      !      !
2SCP
2REL
2FRE 2
2FRQ 2 0 4 CP2 1000 2000 5000 10000
2STO 1 1 1 0 1
IDEN CP1
2NAT 1 1 1 0 1
IDEN CP2
2REG 1 1 1 0 -1
2UNA 1 1 1 0 -1
2IFS 0 1 1 1 1
IDEN Instream Flow
2DIV 1 1 0 1 1
IDEN Irrigation Right
ENDF

```

Table 2.8
First Year of SIM Output File for Example 2

WRAP-SIM (May 2019 Version) OUT Output File
Example 2 - WRAP-SIM Input File Exam2.DAT
Example 2 from Chapter 2 of the Reference Manual

2016	3	2	3	0	0	0	0	1.000						
IF 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0
2016 1	0.000	5760.000	1853.71	110000.00	7613.71	10200.00	0.00	Municipal Right				2304.00	0.00	
2016 1	0.000	0.000	0.00	0.00	0.00	4086.29	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	5760.000	1853.71	110000.00	7613.71	2586.29	0.00	10200.00	2586.29	0.	0.	0.	0.	0
CP2	0.000	0.000	0.00	0.00	0.00	4086.29	0.00	12700.00	5086.29	0.	0.	0.	1000.0	
IF 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
2016 2	0.000	5760.000	1939.98	108840.02	6540.00	6540.00	0.00	Municipal Right				2304.00	0.00	
2016 2	0.000	0.000	0.00	0.00	0.00	2424.00	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	5760.000	1939.98	108840.02	6540.00	0.00	0.00	6540.00	0.00	0.	0.	0.	0.	0
CP2	0.000	0.000	0.00	0.00	0.00	2424.00	2304.00	7660.00	3424.00	0.	0.	0.	1000.0	
IF 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
2016 3	0.000	6720.000	1867.51	103962.50	3710.00	3710.00	0.00	Municipal Right				2688.00	0.00	
2016 3	0.000	1520.000	0.00	0.00	1520.00	2354.00	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	6720.000	1867.51	103962.50	3710.00	0.00	0.00	3710.00	0.00	0.	0.	0.	0.	0
CP2	0.000	1520.000	0.00	0.00	1520.00	834.00	2304.00	4760.00	1834.00	0.	0.	0.	1000.0	
IF 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
2016 4	0.000	6720.000	1749.49	102843.01	7350.00	7350.00	0.00	Municipal Right				2688.00	0.00	
2016 4	1032.000	4560.000	0.00	0.00	3528.00	3528.00	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	6720.000	1749.49	102843.01	7350.00	0.00	0.00	7350.00	0.00	0.	0.	0.	0.	0
CP2	1032.000	4560.000	0.00	0.00	3528.00	0.00	2688.00	9190.00	1000.00	0.	0.	0.	1000.0	
IF 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
2016 5	0.000	7680.000	1989.38	108273.63	15100.00	15100.00	0.00	Municipal Right				3072.00	0.00	
2016 5	0.000	7220.000	0.00	0.00	7220.00	7988.00	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	7680.000	1989.38	108273.63	15100.00	0.00	0.00	15100.00	0.00	0.	0.	0.	0.	0
CP2	0.000	7220.000	0.00	0.00	7220.00	768.00	2688.00	21400.00	1768.00	0.	0.	0.	1000.0	
IF 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
2016 6	0.000	9600.000	2057.75	97519.88	904.00	904.00	0.00	Municipal Right				3840.00	0.00	
2016 6	6062.000	8360.000	0.00	0.00	2298.00	2298.00	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	9600.000	2057.75	97519.88	904.00	0.00	0.00	904.00	0.00	0.	0.	0.	0.	0
CP2	6062.000	8360.000	0.00	0.00	2298.00	0.00	3072.00	1130.00	1000.00	0.	0.	0.	1000.0	
IF 7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
2016 7	0.000	12480.000	1805.56	83346.32	112.00	112.00	0.00	Municipal Right				4992.00	0.00	
2016 7	5487.000	8360.000	0.00	0.00	2873.00	2873.00	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	12480.000	1805.56	83346.32	112.00	0.00	0.00	112.00	0.00	0.	0.	0.	0.	0
CP2	5487.000	8360.000	0.00	0.00	2873.00	0.00	3840.00	145.00	1000.00	0.	0.	0.	1000.0	
IF 8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
2016 8	0.000	11520.000	1458.53	70695.79	328.00	328.00	0.00	Municipal Right				4608.00	0.00	
2016 8	1589.000	5700.000	0.00	0.00	4111.00	4111.00	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	11520.000	1458.53	70695.79	328.00	0.00	0.00	328.00	0.00	0.	0.	0.	0.	0
CP2	1589.000	5700.000	0.00	0.00	4111.00	0.00	4992.00	447.00	1000.00	0.	0.	0.	1000.0	
IF 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
2016 9	0.000	8640.000	1239.39	61788.40	972.00	972.00	0.00	Municipal Right				3456.00	0.00	
2016 9	0.000	1900.000	0.00	0.00	1900.00	3856.00	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	8640.000	1239.39	61788.40	972.00	0.00	0.00	972.00	0.00	0.	0.	0.	0.	0
CP2	0.000	1900.000	0.00	0.00	1900.00	1956.00	4608.00	1220.00	2956.00	0.	0.	0.	1000.0	
IF 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
201610	0.000	7680.000	1078.68	55679.72	2650.00	2650.00	0.00	Municipal Right				3072.00	0.00	
201610	0.000	380.000	0.00	0.00	380.00	3116.00	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	7680.000	1078.68	55679.72	2650.00	0.00	0.00	2650.00	0.00	0.	0.	0.	0.	0
CP2	0.000	380.000	0.00	0.00	380.00	2736.00	3456.00	3310.00	3736.00	0.	0.	0.	1000.0	
IF 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
201611	0.000	7680.000	1122.70	64177.02	17300.00	17300.00	0.00	Municipal Right				3072.00	0.00	
201611	0.000	0.000	0.00	0.00	0.00	6572.00	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	7680.000	1122.70	64177.02	17300.00	0.00	0.00	17300.00	0.00	0.	0.	0.	0.	0
CP2	0.000	0.000	0.00	0.00	0.00	6572.00	3072.00	21800.00	7572.00	0.	0.	0.	1000.0	
IF 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
201612	0.000	5760.000	1114.08	58592.95	1290.00	1290.00	0.00	Municipal Right				2304.00	0.00	
201612	0.000	0.000	0.00	0.00	0.00	2402.00	0.00	Irrigation Right				0.00	0.00	
CP1	0.000	5760.000	1114.08	58592.95	1290.00	0.00	0.00	1290.00	0.00	0.	0.	0.	0.	0
CP2	0.000	0.000	0.00	0.00	0.00	2402.00	3072.00	1620.00	3402.00	0.	0.	0.	1000.0	
IF 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	0.00	0
2017 1	0.000	5760.000	973.36	55249.58	3390.00	3390.00	0.00	Municipal Right				2304.00	0.00	

Table 2.9 begins with two annual summary tables for control points CP1 and CP2. *TABLES* provides options to develop monthly and/or annual summary tables for control points, reservoirs, water rights, selected groups of water rights, or the entire river basin. Quantities from the summary tables are related by volume balances. For example, for simulation year 2017 at control point CP1:

$$\begin{aligned} \text{naturalized streamflow} + \text{return flow} &= \text{storage change} + \text{diversion} + \text{evaporation} + \text{regulated flow} \\ 276,920 \text{ ac-ft/yr} + 0 &= (95,820 - 58,593) + 96,000 + 19,679 + 124,014 \text{ ac-ft/yr} \end{aligned}$$

Stream flow depletions are:

$$\begin{aligned} \text{streamflow depletion} &= \text{diversion} + \text{evaporation} + \text{storage refilling} \\ \text{CP1 2017 streamflow depletion} &= 96,000 + 19,679 + (95,820 - 58,593) = 152,906 \text{ ac-ft/yr} \\ \text{CP2 2017 streamflow depletion} &= \text{diversion} = 38,000 \text{ ac-ft/yr} \end{aligned}$$

Since CP2 is the most downstream gage, the 2017 annual volume balance may be expressed as:

$$\begin{aligned} \text{naturalized flows} + \text{return flows} &= \text{CP1 and CP2 streamflow depletions} + \text{CP2 regulated flows} \\ 345,380 + 38,400 &= 152,906 + 38,000 + 192,874 \end{aligned}$$

A reliability summary table is also included in Table 2.9. This type of table may be developed for diversion or hydropower requirements for individual rights, groups of rights, or all rights at control points or reservoirs. The 96,000 acre-feet/year diversion target at CP1 has no shortages and thus period and volume reliabilities of 100.0%. The monthly diversion requirements for the 38,000 acre-feet/year diversion at CP2 were met during 16 months of the 24-months for which permitted targets were non-zero, with shortages occurring in the other eight months. The period and volume reliabilities shown in Table 2.9 are computed as:

$$\begin{aligned} \text{period reliability} &= [(24-8)/24] 100\% = 66.67\% \\ \text{volume reliability} &= [(38,000-8,372.67)/38,000] 100\% = 77.97\% \end{aligned}$$

The reliability table shows that the diversion at CP2 equals or exceeds 50 percent of the monthly target in 87.5 percent of the months. The annual diversion equals or exceeds 34,200 ac-ft/yr (90% of the annual target of 38,000 ac-ft/yr) during 33.3% of the three years of the period-of-analysis.

The first flow-frequency table in Table 2.9 (bottom of page 36) indicates that regulated monthly stream flows at CP2 vary from 1,000 to 79,758 acre-feet/month, with a mean of 7,666 acre-feet/month. The regulated flow equals or exceeds 1,768 ac-ft during 75% of the 36 months. The second flow-frequency table is in an alternate format in which exceedance frequencies are determined for user-specified flow amounts. Frequency tables may be developed for naturalized, regulated, and unappropriated stream flows, reservoir storage, and instream flow shortage.

The last six tables in Table 2.9 on are illustrative of *TABLES* time series tables of naturalized, regulated, and unappropriated flows; stream flow depletions; diversions, diversion or instream flow shortages; channel losses; or reservoir storage for either control points, reservoirs, water rights, or water right groups. The data may be tabulated as annual rows with monthly columns (page 37) and alternatively in a columnar format (page 38) to facilitate manipulation and plotting in a spreadsheet program such as Microsoft Excel.

Table 2.9
TABLES Output File for Example 2

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP1

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2016	66456.0	2586.3	2586.3	0.0	63869.7	58592.9	19276.8	96000.0	0.0
2017	276920.0	124014.0	122794.0	0.0	152906.0	95819.8	19679.1	96000.0	0.0
2018	113800.0	10579.6	10579.6	0.0	103220.4	84189.6	18850.7	96000.0	0.0
MEAN	152392.0	45726.6	45320.0	0.0	106665.4	79534.1	19268.8	96000.0	0.0

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP2

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2016	85382.0	33778.3	21778.3	36096.0	23830.0	0.0	0.0	23830.0	14170.0
2017	345380.0	192874.0	180874.0	38400.0	38000.0	0.0	0.0	38000.0	0.0
2018	141210.0	49337.6	37337.6	38400.0	27052.0	0.0	0.0	27052.0	10948.0
MEAN	190657.3	91996.6	79996.6	37632.0	29627.3	0.0	0.0	29627.3	8372.7

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET	MEAN	*RELIABILITY*	PERCENTAGE OF MONTHS										PERCENTAGE OF YEARS					
	DIVERSION (AC-FT/YR)	SHORTAGE (AC-FT/YR)	PERIOD VOLUME (%)	WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT										PERCENTAGE OF TARGET DIVERSION AMOUNT					
	(AC-FT/YR)	(AC-FT/YR)	(%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%		
CP1	96000.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
CP2	38000.0	8372.67	66.67	77.97	66.7	66.7	66.7	75.0	87.5	100.0	100.0	33.3	33.3	33.3	33.3	33.3	100.0	100.0	
Total	134000.0	8372.67																	

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	STANDARD MEAN DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE												
		100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM	
CP1	3810.6	12261.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	12370.	64746.
CP2	7666.4	14828.	1000.0	1000.0	1000.0	1000.0	1000.0	1768.0	3028.	3424.	3673.	6472.	19254.	79758.

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS FOR CONTROL POINT CP2

FLOW	FREQ (%)	FLOW	FREQ (%)	FLOW	FREQ (%)	FLOW	FREQ (%)
1000.0	100.00	2000.0	66.67	5000.0	30.56	10000.0	13.89

Table 2.9 (Continued)
TABLES Output File for Example 2

EOP RESERVOIR STORAGE (AC-FT) AT CONTROL POINT CP1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2016	110000.0	108840.0	103962.5	102843.0	108273.6	97519.9	83346.3	70695.8	61788.4	55679.7	64177.0	58592.9	85476.6
2017	55249.6	51641.5	56827.2	91223.0	110000.0	110000.0	110000.0	110000.0	110000.0	109284.4	101323.3	95819.8	92614.1
2018	91823.0	93494.0	86799.8	81110.7	110000.0	104003.3	97602.5	88227.5	79157.0	71980.3	76647.6	84189.6	88752.9
MEAN	85690.9	84658.5	82529.8	91725.6	109424.5	103841.1	96982.9	89641.1	83648.5	78981.5	80716.0	79534.1	88947.9

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2016	12700.	7660.	4760.	9190.	21400.	1130.	145.	447.	1220.	3310.	21800.	1620.	85382.
2017	4160.	3780.	15800.	51600.	78000.	96800.	21200.	26500.	31400.	11900.	1930.	2310.	345380.
2018	4090.	11200.	2140.	3210.	59300.	7160.	10060.	4950.	1380.	2320.	17100.	18300.	141210.
MEAN	6983.	7547.	7567.	21333.	52900.	35030.	10468.	10632.	11333.	5843.	13610.	7410.	190657.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2016	5086.	3424.	1834.	1000.	1768.	1000.	1000.	1000.	2956.	3736.	7572.	3402.	33778.
2017	3074.	2974.	3684.	7428.	45189.	79758.	1996.	12168.	23464.	6166.	3442.	3532.	192874.
2018	3104.	4534.	1354.	1000.	16448.	1000.	1000.	1000.	2998.	3656.	6472.	6772.	49338.
MEAN	3755.	3644.	2291.	3143.	21135.	27253.	1332.	4723.	9806.	4519.	5829.	4569.	91997.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2016	4086.	2424.	834.	0.	768.	0.	0.	0.	1956.	2736.	6572.	2402.	21778.
2017	2074.	1974.	2684.	6428.	44189.	78758.	996.	11168.	22464.	5166.	2442.	2532.	180874.
2018	2104.	3534.	354.	0.	15448.	0.	0.	0.	1998.	2656.	5472.	5772.	37338.
MEAN	2755.	2644.	1291.	2143.	20135.	26253.	332.	3723.	8806.	3519.	4829.	3569.	79997.

DIVERSIONS (AC-FT) FOR WATER RIGHT Irrigation Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2016	0.00	0.00	1520.00	3528.00	7220.00	2298.00	2873.00	4111.00	1900.00	380.00	0.00	0.00	23830.00
2017	0.00	0.00	1520.00	4560.00	7220.00	8360.00	8360.00	5700.00	1900.00	380.00	0.00	0.00	38000.00
2018	0.00	0.00	1520.00	2488.00	7220.00	3602.00	4910.00	5032.00	1900.00	380.00	0.00	0.00	27052.00
MEAN	0.00	0.00	1520.00	3525.33	7220.00	4753.33	5381.00	4947.67	1900.00	380.00	0.00	0.00	29627.33

Table 2.9 (Continued)
TABLES Output File for Example 2

		STO	NAT	REG	UNA	IFS	DIV
		CP1	CP2	CP2	CP2	Instream	Irrigati
2016	1	110000.00	12700.00	5086.29	4086.29	0.00	0.00
2016	2	108840.02	7660.00	3424.00	2424.00	0.00	0.00
2016	3	103962.50	4760.00	1834.00	834.00	0.00	1520.00
2016	4	102843.01	9190.00	1000.00	0.00	0.00	3528.00
2016	5	108273.63	21400.00	1768.00	768.00	0.00	7220.00
2016	6	97519.88	1130.00	1000.00	0.00	0.00	2298.00
2016	7	83346.32	145.00	1000.00	0.00	0.00	2873.00
2016	8	70695.79	447.00	1000.00	0.00	0.00	4111.00
2016	9	61788.40	1220.00	2956.00	1956.00	0.00	1900.00
2016	10	55679.72	3310.00	3736.00	2736.00	0.00	380.00
2016	11	64177.02	21800.00	7572.00	6572.00	0.00	0.00
2016	12	58592.95	1620.00	3402.00	2402.00	0.00	0.00
2017	1	55249.58	4160.00	3074.00	2074.00	0.00	0.00
2017	2	51641.46	3780.00	2974.00	1974.00	0.00	0.00
2017	3	56827.18	15800.00	3684.00	2684.00	0.00	1520.00
2017	4	91223.02	51600.00	7428.00	6428.00	0.00	4560.00
2017	5	110000.00	78000.00	45188.94	44188.94	0.00	7220.00
2017	6	110000.00	96800.00	79757.70	78757.70	0.00	8360.00
2017	7	110000.00	21200.00	1995.59	995.59	0.00	8360.00
2017	8	110000.00	26500.00	12167.79	11167.79	0.00	5700.00
2017	9	110000.00	31400.00	23463.99	22463.99	0.00	1900.00
2017	10	109284.44	11900.00	6166.00	5166.00	0.00	380.00
2017	11	101323.27	1930.00	3442.00	2442.00	0.00	0.00
2017	12	95819.84	2310.00	3532.00	2532.00	0.00	0.00
2018	1	91823.03	4090.00	3104.00	2104.00	0.00	0.00
2018	2	93493.96	11200.00	4534.00	3534.00	0.00	0.00
2018	3	86799.82	2140.00	1354.00	354.00	0.00	1520.00
2018	4	81110.67	3210.00	1000.00	0.00	0.00	2488.00
2018	5	110000.00	59300.00	16447.57	15447.57	0.00	7220.00
2018	6	104003.31	7160.00	1000.00	0.00	0.00	3602.00
2018	7	97602.45	10060.00	1000.00	0.00	0.00	4910.00
2018	8	88227.50	4950.00	1000.00	0.00	0.00	5032.00
2018	9	79156.96	1380.00	2998.00	1998.00	0.00	1900.00
2018	10	71980.34	2320.00	3656.00	2656.00	0.00	380.00
2018	11	76647.65	17100.00	6472.00	5472.00	0.00	0.00
2018	12	84189.59	18300.00	6772.00	5772.00	0.00	0.00

Various variations of the tables included in Table 2.9 as well as a variety of other types of *SIM* simulation results can be created using *TABLES*. Program *TABLES* can also write the time series variables from the *SIM* simulation results, with or without optional adjustments, as binary DSS files which are read by HEC-DSSVue [8]. *SIM* can also record results directly in a DSS file. DSS files can be read only by HEC-DSSVue or other HEC-DSS software. A primary motivation for converting *SIM* simulation results to records in a DSS file is to facilitate convenient plotting using HEC-DSSVue. However, the full spectrum of other HEC-DSS capabilities are available as well as graphics.

Measures of Water Availability and Reliability

WRAP-SIM is applied to assess capabilities for satisfying water supply, hydroelectric power, environmental instream flow, and reservoir storage needs. The future is of concern, rather than the past. However, since future hydrology is unknown, historical stream flows and reservoir evaporation-precipitation rates are adopted as being representative of the hydrologic characteristics of a river basin. Thus, for most typical applications, *SIM* simulates capabilities for meeting specified water management and use requirements during an assumed hypothetical repetition of historical hydrology, represented by sequences of monthly naturalized stream flows and net evaporation less precipitation rates covering a selected hydrologic period-of-analysis.

The main simulation results from a *WRAP-SIM* simulation as organized by program *TABLES* are discussed in Chapter 5. Additional auxiliary *WRAP-SIM* simulation results and analysis capabilities are covered in Chapter 6. Many different optional analysis methods and variations thereof are provided by *WRAP* for assessing water availability and reliability. Key fundamental concepts related to these simulation and analysis methods are introduced in this section of the present Chapter 2.

Program *SIM* simulation results include hydrologic period-of-analysis sequences of monthly values for the variables listed in Table 2.1 and defined in detail in Chapter 5. A majority of the variables associated with water rights can be summed within *SIM* by control point or reservoir. Program *TABLES* allows simulation results associated with water rights to be aggregated by specified groups of rights. *TABLES* reads *SIM* input and output files, computes reliability indices and frequency relationships, and creates tables organizing and summarizing the simulation results as discussed in Chapters 5 and 6.

Simulation studies are organized in a variety of ways to develop an understanding of the river basin system. Model runs demonstrate the effects of alternative water use scenarios and management strategies. Simulation results may be organized in various formats including: the entire time sequences of monthly values of various variables; annual summaries; period-of-analysis means; monthly, annual, or period-of-analysis water budgets; reliability indices; and frequency relationships. These forms of information may all be useful in analyzing, interpreting, and applying the results of a simulation study to support decision-making processes. Simulation results are typically viewed from the perspectives of frequency, probability, percent-of-time, or reliability of meeting water supply, instream flow, hydropower, and/or reservoir storage targets.

Volume and Period Reliability

Concise measures of reliability are useful in analyzing and displaying simulation results. A reliability summary is specified in *TABLES* with a *2REL* record as illustrated by Table 2.9. This table may be created for either water supply diversion or hydroelectric energy generation targets for individual water rights, the aggregation of all rights associated with individual reservoirs or control points, groups of selected rights, or the aggregation of all rights in the model. Program *TABLES* computes alternative variations of both period reliabilities based on percent-of-time and volume reliabilities based on percent of diversion volumes or hydroelectric energy amounts as explained in Chapter 7.

Volume reliability is the percentage of the total target demand amount that is actually supplied. For water supply diversions, the amounts are volumes. For hydroelectric power, the amounts are kilowatt-hours of energy generated. Volume reliability (R_V) is the ratio of volume supplied or energy supplied (v) to the volume or energy target (V), converted to a percentage.

$$R_V = \frac{v}{V} (100\%) \quad (2.2)$$

Equivalently, for water supply, R_V is the mean actual diversion rate as a percentage of the mean target diversion rate. For hydropower, R_V is the mean actual rate of energy production as a percentage of the mean target energy production rate.

Period reliability is based on counting the number of periods of the simulation during which the specified demand target is either fully supplied or a specified percentage of the target is equaled or exceeded. A reliability summary includes tabulations of period reliabilities expressed both as the percentage of months and the percentage of years during the simulation during which water supply diversions (or hydroelectric energy produced) equaled or exceeded specified magnitudes expressed as a percentage of the target demand. The various variations of period reliability (R_P) are computed by *TABLES* from the results of a *SIM* simulation as:

$$R_P = \frac{n}{N} (100\%) \quad (2.3)$$

where n denotes the number of periods during the simulation for which the specified percentage of the demand target is met, and N is the total number of periods. *2REL* record options allow N and n to be defined either considering all months or only months with non-zero demand targets.

A *TABLES* reliability summary includes tabulations of period reliabilities expressed both as the percentage of months and the percentage of years during the simulation during which diversions (or energy produced) equaled or exceeded specified magnitudes expressed as a percentage of the target demand. For example, the table shows the percentage of months in the simulation for which the computed diversion equals or exceeds 75% of the monthly diversion target. It also shows the percentage of years for which the total diversions during the year equal or exceed 75% of the annual permitted amount. The table also shows the percentage of months for which the demand is fully 100% met, without shortage.

Thus, period reliability R_P is an expression of the percentage of time that the full demand target or a specified portion of the demand target can be supplied. Equivalently, R_P represents the likelihood or probability of the target being met in any randomly selected month or year. The period reliability R_P is the complement ($R_P=1-F$) of the risk of failure (F) that the demand target or specified percentage of the target will not be met.

The firm (safe or dependable) yield associated with a particular water supply diversion or hydroelectric power production target is defined as the maximum annual demand target that can be met with a reliability of 100.0 percent based on all the premises reflected in the model. Firm yields may be determined by iteratively adjusting a target amount and rerunning *SIM* until the value meeting the definition of firm yield is found. As discussed in Chapter 6, the *FY* record activates a *SIM* option that automates this procedure.

Diversion Shortage Metrics

Period and volume reliability, as defined in the preceding section and applied throughout the *Reference* and *Users Manual*, are fundamental metrics for evaluating water supply capabilities. Volume and period reliability tables are created with the *2REL* record routine in *TABLES*. Other auxiliary metrics presented in Chapter 7 are developed in a supplemental shortage table created by activating an option on the *2REL* record. This auxiliary table includes the following metrics for summarizing shortages in supplying diversion targets for selected *WR* record water rights.

- maximum shortage during the simulation
- vulnerability defined as the average maximum shortage during each year of a long-term simulation or short-term sequence of a conditional reliability modeling (CRM) simulation
- resiliency defined as the inverse of the mean of the average length of shortage periods
- average severity defined as the average sum of consecutive shortages
- average number of failures per year or CRM sequence
- maximum number of consecutive shortages
- shortage index defined as

$$\text{Shortage Index} = \frac{100}{\text{months}} \sum \left(\left(\frac{\text{annual or sequence shortage}}{\text{annual or sequence target}} \right)^2 \right)$$

Frequency Analyses

Frequency tables created with *TABLES 2FRE* and *2FRQ* records are also included in Table 2.9. These tables may be developed for naturalized flow, regulated flow, unappropriated flow, instream flow shortages, reservoir storage, and surface elevation directly without a *DATA* record. A *DATA* record allows frequency analyses for all the variables in the *SIM* simulation results and other datasets created from the simulation results. Frequency tables may be for a specified month of the year such as August or for all months. A *2FRE* record frequency table may be in the row format illustrated in Table 2.9 or in an alternative column format that contains several more frequencies and is convenient to export to a Microsoft Excel spreadsheet.

Exceedance frequency is an expression of the percentage of time that particular flow or storage amounts can be expected to occur. Equivalently, the exceedance frequency represents the likelihood or probability of a certain amount of water being available.

Exceedance frequencies may be determined with Eq. 2.4 based on ranking and counting.

$$\text{Exceedance Frequency} = \frac{n}{N} (100\%) \quad (2.4)$$

where *n* is the number of months during the simulation that a particular flow or storage amount is equaled or exceeded, and *N* is the total number of months considered. Alternatively, *2FRE* record options include modeling the frequency relationship with the log-normal or normal probability distributions based on the computed parameters mean and standard deviation.

The *2FRE* table includes the mean and standard deviation, minimum and maximum, and the flow or storage amounts that are equaled or exceeded specified percentages of the time. *2FRE* tables may be in a row format or in a column format containing additional frequencies. The *2FRQ* table also develops flow-frequency, storage-frequency, elevation-frequency, or instream flow shortage-frequency relationships. However, the model-user enters specified flow or storage values of interest. *TABLES* simply counts the number of months for which a specified amount was equaled or exceeded and applies Equation 2.4 to assign a frequency.

Program *SIM* Options Involving Cyclic Repetitions of the Simulation

The *SIM* simulation computations outlined in Figure 2.2 are discussed earlier in this chapter. A specified scenario of water resources development, allocation, management, and use is simulated during each sequential month of a hydrologic period-of-analysis with stream flow inflows and reservoir net evaporation rates representing historical hydrology for natural conditions or some other specified condition of river basin development. For example, the hydrologic period-of-analysis might be 1940-2016, covering a sequence of 924 months. The simulation begins with January 1940 naturalized stream flows and net evaporation rates and proceeds through the 924 months. In many typical applications, a particular execution of *SIM* involves a single simulation covering the hydrologic period-of-analysis once. However, *SIM* has several optional features that involve two or more repetitions of the hydrologic period-of-analysis simulation automated within a single execution of *SIM*.

With one or more of the following optional features activated, the simulation is automatically repeated two or more times with a single execution of *SIM*.

- Dual simulation options activated by the *JO*, *SO* or *PX* records and described in Chapter 4 of this *Reference Manual*.
- Yield-reliability analysis routine activated by the *FY* record as outlined in Chapter 6.
- Beginning-ending storage options activated by the *JO* record and described in Chapter 6 of this *Reference Manual*.
- Short-term conditional reliability modeling simulations explained in Chapter 8 of this *Reference Manual*.

The dual simulation and beginning-ending storage features each involve two simulations. The yield-reliability analysis routine may iteratively repeat the simulation any number of times. The conditional reliability modeling routine may also activate multiple repetitions of the simulation.

The simulation is repeated in its entirety from the beginning to the end of the hydrologic period-of-analysis with the four routines noted in the preceding paragraph. Another different *SIM* modeling feature involves a second pass through the water rights priority sequence simulation repeated within individual months. Second pass options activated by instream flow *IF* record parameter IFMETHOD or *JO* record parameter PASS2 and outlined in Chapter 4 involve dual passes through the water right priority loop. As indicated in Figure 2.2, the two passes through the water right computations are embedded within the monthly loop.

CHAPTER 3 HYDROLOGY IN THE SIMULATION MODEL

River system hydrology is represented in *WRAP-SIM* by input sequences of naturalized stream flows and reservoir net evaporation-precipitation depths for each month of the hydrologic period-of-analysis at each pertinent location. This chapter discusses hydrology within the *SIM* simulation. *WRAP-HYD* described in the *Hydrology Manual* is designed to facilitate developing hydrology-related *SIM* input datasets. Both programs include routines for incorporating channel losses in various computations, based on including loss factors for pertinent stream reaches in the input data. The model is based on total stream flows, rather than incremental inflows. However, options are provided in *HYD* and *SIM* to address the issue of negative incremental flows. These hydrology-related features of the model described in this chapter involve stream flow and/or reservoir water surface evaporation less precipitation. Most of the present Chapter 3 focuses on stream flow. Chapter 4 covers aspects of the model dealing with water rights requirements including reservoir storage and water management, allocation, and use.

WRAP-SIM allocates naturalized stream flows to meet specified water right requirements subject to channel losses and losses or gains associated with evaporation from and precipitation onto reservoir water surfaces. A conventional application of *SIM* is based on:

- simulating capabilities for fulfilling specified river regulation and water use requirements for a specified scenario of water resources development infrastructure, reservoir system operating rules, and water allocation practices
- during an assumed hypothetical repetition of historical hydrology represented by sequences of monthly naturalized stream flows and reservoir net evaporation-precipitation rates covering a selected hydrologic period-of-analysis.

The future is of concern, rather than the past. However, future hydrology is unknown. Historical stream flows and reservoir evaporation less precipitation rates are adopted as being representative of the hydrologic characteristics of a river basin that can be expected to continue into the future. A typical hydrologic period-of-analysis used for studies in Texas is 1940 to near the present. This period includes the 1950-1957 most severe drought-of-record for much of Texas as well as a full range of fluctuating wet and dry periods. Water resources are highly variable and highly random, subject to extremes of droughts and floods as well as continuous more normal fluctuations. Major droughts typically involve long periods with sequences of many months of low flows. A basic premise of the conventional modeling approach is that historical naturalized stream flows and evaporation-precipitation rates for an adequately long period-of-analysis capture the essential statistical characteristics of river basin hydrology.

WRAP is a river/reservoir system model with little capability for simulating groundwater or surface/subsurface water interactions. However, some interactions between stream flow and subsurface water may be modeled. Channel loss features are described in this chapter. Water supply return flows covered in Chapter 4 may originate from groundwater sources. Groundwater return flows may be modeled using constant inflow *CI* records or as a *WR* record type 4 right. Changes in spring flows or stream base flows associated with aquifer pumping or management scenarios, simulated with a groundwater model, may be treated as adjustments to naturalized stream flows contained in a *WRAP-SIM* flow adjustment file.

Naturalized Stream Flow

A *WRAP-SIM* simulation begins with homogeneous sequences of monthly stream flow volumes covering the hydrologic period-of-analysis at all control points. Program *HYD* provides a set of optional routines for developing or updating homogeneous stream flow datasets for input to *SIM*. For each control point, stream flows must be either provided as input to *SIM* or computed within *SIM* from flows at one or more other control points using the flow distribution techniques that are incorporated in both *HYD* and *SIM* and described later in this chapter. No limits are imposed on the length of the period-of-analysis. Any units may be used in combination with appropriate conversion factors. Typical English units for stream flow are acre-feet/month. Reasonable metric units for stream flow are thousand cubic meters per month.

Homogeneous Stream Flow Sequences

Homogeneous means that the flows represent a specified uniform condition of watershed and river system development, long-term climate, and water use. Non-homogeneities in historical gaged stream flows are typically caused primarily by construction of reservoir projects, growth or changes in water use, and other changes in water management practices over time. However, watershed land use changes, climate changes, and other factors may also affect the homogeneity of recorded stream flow measurements. Flows observed at gaging stations during past years may be adjusted to develop flow sequences representing a specified scenario of water resources development and management, water use, watershed land use, climate, and hydrologic conditions.

The stream flows in the *SIM* input dataset (*IN* records in FLO file or DSS file) may be naturalized flows representing natural hydrology unaffected by water resources development and management. Alternatively, the stream flow inflows input to the river/reservoir system simulation model may represent some other specified homogeneous condition of river basin development. The basic concept is to provide a homogeneous set of flows as input to *SIM* representing hydrology for a specified condition of river basin development. The stream flows in the *SIM* input dataset should represent flows unaffected by the reservoirs, diversions, return flows, and other water management practices and water use reflected in the *SIM* water rights input dataset. Typically, *SIM* stream flow input datasets represent natural hydrology without human impact but alternatively may reflect other scenarios of river basin hydrology, depending on the particular application. The term *naturalized* flow may be applied generically to refer to any stream flows adopted for a *SIM* input dataset.

The objective of the stream flow naturalization process is to develop a homogeneous set of flows representing natural river basin hydrology. Historical observed flows are adjusted to remove nonhomogeneities caused by human activities. Naturalized stream flows represent the natural flows that would have occurred in the absence of the water users and water management facilities and practices reflected in the *SIM* water rights input dataset.

Developing naturalized flows typically represents a major portion of the effort required for a creating a *SIM* input dataset. The extent to which observed historical flows are naturalized is based largely on judgment. In extensively developed river basins, quantifying and removing all effects of human activities is not possible. For sites with relatively undeveloped watersheds, little or no adjustments may be necessary.

Sequences of monthly flows representing historical natural hydrology are typically developed by adjusting recorded flows at gaging stations to remove the past impacts of upstream major reservoirs, water supply diversions, return flows from surface and ground water sources, and possibly other factors. In most typical major river basins, numerous smaller reservoirs have been constructed over many decades, but most of the storage capacity is contained in a relatively few large reservoirs. Decisions are required regarding which reservoirs to include in the adjustments. Major water supply diversions and return flows are typically also included in the flow adjustments.

Other types of adjustments may be made as well. For example, land use changes such as clearing forests and urbanization or climate change due to global warming may significantly affect stream flow. A watershed model such as the *Soil and Water Assessment Tool (SWAT)* may be used to quantify the impacts of land use changes on stream flows. A global circulation model reflecting climate change can be applied in combination with the *SWAT* precipitation-runoff model to adjust *WRAP* naturalized stream flows for alternative scenarios of future long-term climate change [28].

Without adequate historical gaged stream flow records, naturalized flows representing a specified condition of watershed development may be synthesized from precipitation data with a watershed precipitation-runoff model such as *SWAT*. However, adjusting gaged flows to remove nonhomogeneities is generally more accurate than synthesizing flows with a watershed model.

WRAP Features for Developing Flow Datasets

The following tasks are involved in developing the sequences of monthly naturalized flows covering the hydrologic period-of-analysis at all control points required for a *SIM* simulation.

1. developing sequences of naturalized flows at stream gaging stations using *HYD*
2. synthesizing flows for gaps of missing data and extending record lengths outside of *WRAP*
3. distributing naturalized flows from gaged to ungaged locations within either *HYD* or *SIM*

WRAP includes routines to assist with the first and third task, but not the second. Various gaging stations have different periods-of-record, and there may be gaps with missing data. The second task consists of extending flow sequences and reconstituting missing data using regression techniques with data from other gages and other months at the same gage. Regression analysis capabilities are readily available in other computer software packages such as *HEC-DSSVue* and *Microsoft Excel*.

As discussed in the *Hydrology Manual*, program *HYD* writes monthly stream flows as a set of inflow *IN* records in a text file or as binary records in a Data Storage System (DSS) file for input to *SIM*. *HYD* provides various hydrology data compilation capabilities, which among other capabilities include options for:

- converting observed gaged stream flows to naturalized stream flows
- distributing flows from gaged to ungaged locations using techniques that are also included in *SIM*
- adjusting stream flows to extend the hydrologic period-of-analysis or to develop condensed datasets
- updating the hydrologic-period-of- analysis by extending naturalized flows based on measured monthly precipitation and evaporation rates

Reservoir Evaporation-Precipitation

Evaporation from a reservoir and precipitation falling directly on the reservoir water surface are combined as a net evaporation minus precipitation. Net evaporation less precipitation volumes are computed by multiplying the reservoir water surface area by net evaporation-precipitation rates provided on *EV* records in dimensions of depth/month. Various units may be used. Typical units include water surface area in acres, evaporation-precipitation rates in feet/month, and volumetric rates in acre-feet/month. Computation of evaporation-precipitation volumes are incorporated in *SIM* reservoir volume accounting routines as described in the Chapter 4 section entitled *Iterative Reservoir Volume Balance Computations*.

Within the *SIM* simulation, net evaporation minus precipitation volume is included in the monthly water accounting computations performed in the water rights simulation loop. Average water surface area is determined as a function of storage content at the beginning and end of the month. Since both end-of-month storage and net evaporation-precipitation volumes are unknowns in the computations, an iterative solution algorithm is required.

Adjusted Net Evaporation-Precipitation

SIM and *HYD* include options to account for the fact that a portion of the precipitation falling on the reservoir water surface is also reflected in the naturalized stream flows. Without a reservoir, the runoff from the land area of the non-existent reservoir contributes to stream flow. However, only a portion of the precipitation falling at the reservoir site contributes to stream flow. The remainder is lost through infiltration and other hydrologic abstractions. With the reservoir in place, all of the precipitation falling on the water surface is inflow to the reservoir.

SIM and *HYD* options include adjustments in the reservoir volume balance computations for the runoff from the land area covered by a reservoir that would have occurred without the reservoir. This adjustment in *HYD* may be incorporated with other adjustments in removing the historical effects of reservoirs in the process of converting gaged stream flows to naturalized flows. The option in *SIM* accounts for the portion of the reservoir surface precipitation that is already reflected in the naturalized stream flow inflows. In a typical application mode, the *HYD* adjustment is added to historical stream flows to determine naturalized stream flows. In *SIM*, the adjustment reduces available water amounts to prevent *double-counting* which would occur inappropriately if the runoff from the reservoir site is included in both the naturalized stream flows (*IN* records) and precipitation falling on the reservoir water surface (*EV* records).

The procedure in *SIM* for adjusting net evaporation-precipitation depths for runoff from reservoir sites are outlined as follows.

- Net evaporation minus precipitation depths are input on *EV* records in an EVA file or as binary records in a DSS file.
- A precipitation-runoff adjustment term is computed within *SIM* to prevent *double-counting* the reservoir surface precipitation that is already in the *IN* record naturalized flows. *JD* record field 10 (*EPADJ*) and *CP* record field 10 (*EWA*) activates this option. The *JD* record *EPADJ* sets the default option applied to all control points for which the *CP* record *EWA* is left blank.

An entry for *EWA* on a *CP* record overrides the default option set by *EPADJ* on the *JD* record. Without the *JD* and *CP* record entries, the adjustment option is not applied.

- The precipitation-runoff adjustment requires a drainage area and corresponding naturalized stream flows. An effective total watershed area may be input as a positive number in *CP* record field 10 for use with the total naturalized flows at that control point. Alternatively, the incremental or total watershed area and corresponding incremental or total naturalized flows for either the ungaged (*FD* record field 2) or gaged (*FD* record field 3) control points may be used by entering a -1 or -2 in *CP* record field 10 (applicable to that control point) or *JD* record field 10 (default for all control points). Incremental flows and watershed areas determined based on information from the *FD* and *WP* records are identically the same for the rainfall-runoff adjustments as for distributing stream flows from gaged to ungaged sites.

Within the *SIM* simulation, the portion of the naturalized stream flows derived from precipitation falling on dry land, that is now in the model covered by the reservoir, is determined by an algorithm that is conceptually identical to the drainage area ratio method for transferring stream flow. Although a drainage area ratio is not actually computed, the method is conceptually the same. *SIM* performs the adjustment computations for each month as follows.

1. A stream flow per unit drainage area or runoff depth (in feet/month) is computed by dividing the total or incremental monthly naturalized stream flow (in acre-feet/month) by the watershed area from the *CP* record or *FD/WP* records.
2. The runoff depth computed in step 1 above is added to the net evaporation-precipitation rate read from an *EV* record. Thus, the adjusted net evaporation-precipitation rate is the evaporation rate minus precipitation rate plus rainfall-runoff depth computed in step 1 above.
3. The algorithms for determining net evaporation volumes and performing the reservoir volume accounting remain unchanged. The only difference is that the *EV* record net evaporation-precipitation rates input to the computations have been adjusted as noted above. The net evaporation-precipitation volume is determined by multiplying the reservoir water surface area by the adjusted net evaporation-precipitation depth.

Allocation of Stream Flow

The *WRAP-SIM* simulation process is outlined in Figure 2.2 of Chapter 2. A *SIM* simulation begins each month with sequences of monthly stream flow volumes at each control point representing natural hydrology or some other specified condition of river basin development. These stream flows typically represent unregulated natural historical hydrology and are called **naturalized flows**. For each month of the simulation, stream flows are allocated to meet the water rights requirements described in Chapter 4. **Regulated** and **unappropriated flows** are computed for each **control point** for each month of the period-of-analysis. **Available flows** and **stream flow depletions** are computed for each **water right** for each month of the period-of-analysis. The basic stream flow-related variables computed within *SIM* are defined as follows.

Regulated flows represent the actual physical stream flow at a control point location after accounting for all of the water rights. Given all of the water right requirements and other premises reflected in the model, the regulated flows are the monthly stream flow volumes that would be measured by a gaging station at the control point.

Unappropriated flows represent the monthly flow volumes still available for appropriation after considering all water rights requirements. In a particular month, the unappropriated flow at a control point may be less than the regulated flow because a portion or all of the flow may have been committed to meet instream flow requirements at that control point or for use further downstream. The unappropriated flow is the portion of the regulated flow that is not needed to meet the water rights requirements included in the simulation. Unappropriated flows represent water available for additional new water right applicants.

Available flows represent the amount of water available to a particular water right in the priority based water rights allocation. The available flow for a right is affected by more senior rights and is determined based on the still uncommitted flows at the right's control point and all downstream control points. At the beginning of the monthly simulation loop, the available flow for the most senior water right is the naturalized flow plus return flow from the previous month, if any. At the completion of the water rights computational loop, after considering the most junior water right, available flows become the unappropriated flows.

Stream flow depletions are the stream flow amounts appropriated to meet diversion requirements, account for reservoir net evaporation-precipitation, and/or refill reservoir storage. A stream flow depletion volume in a given month will often include refilling of reservoir storage capacity depleted during previous months. A negative stream flow depletion may occur if the input net evaporation less precipitation depth is negative, meaning precipitation falling on a reservoir water surface exceeds evaporation. A negative stream flow depletion means that reservoir surface precipitation volume added to the stream flow exceeds the evaporation, diversion, and reservoir refilling volumes that deplete the stream flow. Each stream flow depletion is associated with a particular water right. Unappropriated flows are the portions of the naturalized flows still remaining after accounting for stream flow depletions, instream flow requirements, and return flows for all water rights.

A *SIM* simulation begins with hydrologic period-of-analysis sequences of monthly naturalized (unregulated) flow volumes at each control point provided as input or computed within *SIM* using flow distribution methods covered later in this chapter. Regulated and unappropriated flow volumes are computed from the naturalized flows through a series of adjustments reflecting the effects of water rights requirements and associated reservoir storage. As illustrated in Figure 2.2, the *SIM* water allocation computations are performed in a water rights loop embedded with a period (monthly time step) loop. *SIM* computes available flows and stream flow depletions associated with each water right and unregulated and unappropriated stream flows associated with each control point. As each water right is considered, the available stream flow is determined based on yet uncommitted flows at its control point and all downstream control points. After the stream flow depletion for the right is determined, the flows at the control point and all downstream control points are adjusted for the flow depletion and return flow.

Channel Losses

Channel losses represent the portion of the stream flow in the reach between two control points that is lost through infiltration, evapotranspiration, and diversions not reflected in the water rights. The naturalized flows input on *IN* records are typically determined based on adjusting observed flows at gaging stations to remove the effects of human water management. Thus, the

naturalized flows should already reflect natural channel losses. In *SIM*, a stream flow depletion (diversion and/or refilling reservoir storage) at a control point results in a reduction in the water available at that control point and all downstream control points. In reality, a portion of the water diverted or stored may not reach the downstream sites anyway due to channel losses. Also, diversion return flows and reservoir releases may be diminished prior to reaching downstream locations. Channel losses are included in several *SIM* routines to address these situations. Channel losses may also be included in the *HYD* stream flow naturalization adjustments discussed earlier in this chapter. A channel loss option is also included in the flow distribution methods, described later in this chapter, incorporated in both *HYD* and *SIM*.

Channel loss L is treated as a linear function of the flow $Q_{upstream}$ at the control point defining the upstream end of the channel reach.

$$L = F_{CL} Q_{upstream} \quad (3.3)$$

By definition, the channel loss coefficient F_{CL} should range from 0.0 to 1.0. F_{CL} for the river reach below a control point is input as variable CL in field 11 of the control point CP record. All control points are internally assigned a default CL of zero, with the user providing the CL on the CP records for any control points with non-zero values. As discussed below, this linear stream flow versus loss relationship and CP record loss factor is incorporated in several routines in programs *SIM* and *HYD*. The *TABLES* 1CPT routine includes an option for displaying channel loss factors (F_{CL}) and cumulative delivery factors $[(1.0 - F_{CL1})(1.0 - F_{CL2}) \dots (1.0 - F_{CLN})]$.

Channel Losses in WRAP-SIM

Channel losses affect regulated flows, unappropriated flows, available flows, and other variables computed within *SIM*. Channel losses are reflected in the simulation from two perspectives.

1. Channel losses reduce the stream flows associated with return flows, *CI* and *FA* record positive inflows, releases from reservoir storage for downstream diversions or hydroelectric power generation. These losses represent **decreases** in stream flows to result from incorporation of channel losses in the model.
2. Channel loss **credits** represent the "*reduction in the reduction*" in stream flows at downstream locations associated with upstream stream flow depletions for diversion and storage rights and *CI* record outflows (negative inflows). **Credits** represent **increases** in stream flows to result from incorporation of channel losses in the model. In the simulation computations, flows at downstream control points are reduced by the amount of upstream stream flow depletions for diversions and filling reservoir storage. **Credits** represent the amount of the stream flow depletion that would not have reached the downstream location anyway due to channel losses.

Both channel loss credits and channel losses are computed and written to the output file within the *SIM* water rights and period loops. The total of the channel loss credits for each month at each control point are written in the control point output record. Likewise, the total monthly channel losses are written in field 12 of the control point records in the *SIM* output file. Program

TABLES reads the *SIM* output file and builds user-specified tables which may include the channel losses and credits. The difference between the credits tabulated by a *2CLC* record and losses tabulated by a *2CLO* record is as follows.

- The monthly flows in a table developed by a channel loss credit *2CLC* record for a specified control point represent the total channel losses in the reach below the control point associated with stream flow depletions at upstream control points for diversions and refilling reservoir storage. These loss credits represent channel losses reflected in the *IN* record stream flows that did *not* actually occur in the simulation because the diversion or reservoir refilling reduced the downstream flows and corresponding channel losses.
- The monthly flows in a table developed by a channel loss *2CLO* record for a specified control point represent the total channel losses in the reach below the control point associated with diversion return flows, *CI* record constant inflows, and releases from reservoir storage. These flows represent reductions in stream flow in the model.

Computational algorithms related to channel losses are incorporated in flow adjustment, available flow determination, flow distribution and other routines. As previously discussed, in *SIM*, regulated flows and unappropriated flows are computed through a series of cumulative adjustments starting with the naturalized flows provided as input. The stream flow volumes change in response to the effects of each water right as it is considered in turn in the water rights computation loop. The channel loss computations are performed in conjunction with (1) determining the amount of water available to a right and (2) making adjustments to regulated and unappropriated flows at each downstream control point reflecting the effects of upstream:

- stream flow depletions for diversions and/or refilling of reservoir storage
- constant inflows or outflow input on *CI* or *FA* records
- return flows
- releases from storage in secondary reservoirs at upstream control points for diversions downstream
- releases from reservoir storage for hydroelectric power generation
- reservoir spills associated with seasonal rule curve operations

Releases may be made from reservoirs located some distance upstream of a diversion site as necessary to supplement the stream flow available at the diversion site. *SIM* considers channel losses in determining the amount to release from the reservoir or multiple reservoirs. The reservoir release amount is set to meet the diversion requirement after channel losses.

As discussed later in this chapter, channel losses may also be incorporated in the computational routines for distributing naturalized flows from gaged to ungaged locations. The flow distribution routines are the same in this respect in *SIM* and *HYD*.

The channel loss credit computations for adjustments to regulated and unappropriated flows associated with stream flow depletions for diversion and storage rights are described below. Similar algorithms compute channel losses associated with return flows and releases from reservoir storage. Channel losses are also considered in another computation. In the water rights

computational loop, as each right is considered in turn, the allocation computations begin by calling the subroutine that determines the amount of water available to the right. The amount of water available depends on yet unappropriated flows at the control point of the water right and at all downstream control points. Channel loss credits for stream flow depletions associated with the right are included in determining the amount of water available to the right.

The effects of a stream flow depletion D , for a diversion or refilling storage, are carried downstream by reducing the amount of water available A at all downstream control points by the amount of the stream flow depletion D . Without channel losses, the amount of water available $A_{adjusted}$ at a control point is adjusted for a stream flow depletion D occurring upstream as follows.

$$A_{adjusted} = A - D \quad (3.4)$$

With channel losses, the water available A at downstream control points is reduced by the upstream depletion D less the channel loss L , where $L = C_L D$.

$$A_{adjusted} = A - (D - F_{CL} D) = A - (1.0 - F_{CL}) D \quad (3.5)$$

The term $(1.0 - F_{CL})$ is a delivery factor defined as the fraction of the flow at the upstream control point that reaches the next downstream control point. For control points in series, the channel losses in each individual reach ($L_i = F_{CL_i} D$) are considered in adjusting water availability to reflect upstream diversions and storage. The water available A at the N th control point below the stream flow depletion is adjusted as follows, where $F_{CL1}, F_{CL2}, F_{CL3}, \dots, F_{CLN}$ denote the channel loss coefficients for each of the N individual reaches between the control point at which the stream flow depletion D occurs and the control point at which the amount of available water A is being adjusted.

$$A_{adjusted} = A - [(1.0 - F_{CL1})(1.0 - F_{CL2})(1.0 - F_{CL3}) \dots (1.0 - F_{CLN})] D \quad (3.6)$$

The effects of channel losses on return flows, hydropower releases, and releases from secondary reservoirs are handled similarly. With respect to return flows and hydropower releases, the channel losses are reflected in the adjustments to the regulated and unappropriated flows at all downstream control points. Releases from secondary reservoirs, with associated channel losses, affect regulated flows at control points located below the reservoir but above the diversion.

Channel Losses in WRAP-HYD

Channel losses are incorporated in the following routines in *HYD*.

1. stream flow naturalization adjustments
2. distribution of flows from gaged to ungaged locations

In developing naturalized flows, the adjusted flow $F_{adjusted}$ at the control point of the diversion, reservoir, or other adjustment is the original flow F plus an adjustment amount A_F . Without channel losses:

$$F_{adjusted} = F + A_F \quad (3.7)$$

The stream flow at the N th control point below the diversion, reservoir, or other adjustment is adjusted as follows, where $C_{L1}, C_{L2}, C_{L3}, \dots, C_{LN}$ denote the channel loss coefficients for each of

the N individual reaches between the control point at which the flow adjustment A_F occurs and the control point at which the stream flow F_{adjusted} is being adjusted.

$$F_{\text{adjusted}} = F + [(1.0 - F_{\text{CL1}}) (1.0 - F_{\text{CL2}}) (1.0 - F_{\text{CL3}}) \dots (1.0 - F_{\text{CLN}})] A_F \quad (3.8)$$

Methods for Establishing Stream Flow Inflows

A *SIM* simulation begins with river system inflows representing natural hydrology or some other specified condition of river basin development. Since these flows typically represent natural hydrology, they are called *naturalized flows*. Stream flow operations within *HYD* involve adjustments to convert historical gaged flows to naturalized flows or extending naturalized flow sequences. These flows may be transferred within either *HYD* or *SIM* to ungaged control points.

The input variable *INMETHOD(cp)* on the *SIM* or *HYD* control point *CP* record controls selection of the options listed in Table 3.1 for assigning naturalized flows to each control point. Option 1 consists of providing flows in a *SIM* input file for a control point, which is called a primary control point. Option 2 is to repeat flows at multiple control points as specified by the *CP* record. Options 3 through 8 and 10 in Table 3.2 involve distributing flows from a primary control point to a secondary control point using input data from *FD*, *FC*, and/or *WP* records in a *DIS* file. Option 9 is applicable only to *SIM*. The other options are the same in *HYD* and *SIM*. *CP* record fields 11 and 13 in *SIM* allow the flows to be replaced by a specified constant flow.

Table 3.1
Methods for Establishing Stream Flow Inflows

-
- 1 Naturalized flows at the control point are provided as input data on *IN* records.
 - 2 Flows from another control point are repeated without change except for a multiplier.
 - 3 Equation 3.10 is used to compute flows: $Q_{\text{ungaged}} = a (Q_{\text{gaged}})^b + c$
 - 4 The modified NRCS CN method (Eq. 3.16) is used. The computed flows at the ungaged control point are limited to not exceed the flows at the gaged (known-flow) control point.
 - 5 The modified NRCS CN method is used. The computed flows at the ungaged control point are not constrained to not exceed the flows at the gaged (known-flow) CP.
 - 6 Equation 3.11 incorporating a channel loss coefficient into the drainage area ratio method is used. Drainage areas are entered on *WP* records. F_{CL} is from *CP* record.
 - 7 Equation 3.9 with ratio of drainage areas from *WP* records. $Q_{\text{ungaged}} = R_{\text{DA}} Q_{\text{gaged}}$
 - 8 An iterative algorithm incorporates channel losses in the NRCS CN method.
 - 9 Flows are not provided for this control point.
 - 10 Flows are computed in proportion to flows at other control points with Eq. 3.23.
-

The *CP* record field 6 default option 1 listed in Table 3.1 consists of providing flows for the control point as input for either *SIM* or *HYD*, which may be in the form of inflow *IN* records in a text file (FLO, DAT, HYD files) or as binary records in a DSS file. At least one *SIM* control point must be assigned flows based on option 1. The term *primary control point* is applied to control points for which flows are provided as input. *Secondary control points* have flows computed within *SIM* based on flows at primary control points provided in a *SIM* input file.

Option 2 for either *SIM* or *HYD* consists of repeating the flows already input or computed for another control point identified in *CP* record field 7, with the option of applying the multiplication factor entered in the *CP* record field 4. The multiplication factor could be a unit conversion factor, drainage area ratio, or other flow distribution factor. With the default multiplication factor of 1.0, the flows at the primary control point are duplicated at the secondary control point without modification. *CP* record field 7 also allows values of zero to be assigned to the naturalized flows at a secondary control point.

Option 9 applicable only to *SIM* (not *HYD*) allows a control point to be included in the input dataset without being assigned stream flows. In most typical applications, there is no need for including control points in the model without assigning stream flows. Water rights and reservoirs are assigned to appropriate control point locations that define the stream flow available to them. However, option 9 is available for unusual situations in which control points are included in a model without stream flows being assigned. Option 9 is very different than assigning zero values for stream flows.

Option 9 affects the basic *SIM* simulation computations as follows. As each water right is considered in priority sequence in the simulation, the amount of stream flow available to the water right is computed considering flows at the control point of the right and all downstream control points with the exception of option 9 control points. Any control point assigned option 9 in *CP* record field 6 is skipped (not considered) in determining stream flow availability for water rights. The naturalized, regulated, and unappropriated flows are zero at an option 9 control point, but this does not constrain flow availability for water rights. Flows available to water rights located at an option 9 control point are controlled only by flows at downstream control points. Likewise, an option 9 control point does not affect flow availability for upstream rights.

Distribution of Naturalized Flows from Gaged to Ungaged Control Points

The term *flow distribution* refers to the computation within *SIM* or *HYD* of naturalized stream flows at a control point based upon known naturalized flows at one or more other control points. As discussed in the preceding section, *SIM* and *HYD* control point *CP* record field 6 controls the specification of method for assigning flows. The alternative methods for distributing naturalized flows from gaged (known-flow) to ungaged (unknown-flow) control points are listed as options 3 through 8 and 10 in Table 3.1. Input parameters are provided on flow distribution *FD*, flow distribution coefficients *FC*, and watershed parameter *WP* records stored in a DIS file.

Stream flows may be distributed from gaged (primary, source, known-flow) to ungaged (secondary, unknown-flow) control points within either programs *HYD* or *SIM* using the same methodologies. The flow distribution computations are the same in *HYD* and *SIM*, but the computed flows are output in a different format. *HYD* provides capabilities for developing *SIM*

hydrology datasets (*IN* and *EV* records in text files or binary records in a DSS file) for specified control points from given inflow *IN* and evaporation rate *EV* records at other control points. The synthesized flows are output along with the known flows. Conversely, if naturalized flows are synthesized within *SIM*, the inputted and computed naturalized flows are output to the *SIM* output file and read by *TABLES* just like all the other simulation output.

With *INMETHOD(cp)* options 3 through 8, sequences of monthly flow volumes for a specified secondary (unknown flow) control point are computed from either incremental sub-watershed or total watershed flows at another specified single control point called the source control point. Sub-watersheds for a single source control point are defined in basically the same manner for either of the options 3-8. Option 10 synthesizes flows at a secondary control point as a function of flows at any number of source control points without explicitly delineating local incremental sub-watersheds.

Incremental Watersheds

The alternative flow distribution methods may be applied to either local incremental stream flows or the total flows at the pertinent control points. The local incremental subwatersheds above the gaged and ungaged control points are delineated by specifying upstream control points. If local incremental subwatersheds are adopted, the unknown flow at an ungaged control point is determined from the known flow at a gaged control point in three steps.

1. The incremental flow at the gage is computed by subtracting the total flow at the gage from the sum of flows at appropriate upstream gages, adjusted for channel losses if channel loss factors are non-zero.
2. The incremental flow at the gage, computed in step (1), is distributed to the ungaged site using one of the alternative *INMETHOD(cp)* options 3-8 listed in Table 3.1.
3. The incremental flow at the ungaged site, computed in step (2), is added to the flows at appropriate upstream control points, adjusted for channel losses, to obtain the total flows at the ungaged site.

Watershed parameters for distributing flows are provided on flow distribution coefficient *FC* and watershed parameter *WP* records. The inputted watershed parameters may correspond to either the entire watershed above a control point or to the incremental local watershed between control points. The flag *INWS(cp)* on the *CP* record for the ungaged control point indicates whether the parameters on the *FC* or *WP* record are for the total watershed or incremental watershed. If the inputted watershed parameters are for total watersheds, parameter values for incremental watersheds are computed by the model as required. If the watershed parameters provided as input are for incremental watersheds, the user must specify the corresponding control points for computing incremental stream flows.

Example 4 in Appendix C and the schematic and equations shown in Figure 3.1 illustrate the scheme by which *HYD* and *SIM* allow the user to define incremental watersheds on *FD* records for use in distributing flows. Figure 3.1 also serves as the schematic for Example 4 in Appendix C designed to demonstrate flow distribution features. In Figure 3.1, flows are known at gaged control points (CPs) J, K, L, M, and N and must be computed at ungaged control points I, II, III,

and IV. The WRAP methodology allows the user to select the gaged control points from which to distribute flows. Flows at either of the four ungaged sites (control points I, II, III, IV) may be computed by transferring total flows from either of the five gaged control points or alternatively from the incremental local watershed above control point (CP) N. For example, flow and drainage area equations are shown in the figure for computing flows at CP I using the incremental watersheds above CP I and CP N.

- I ungaged (unknown flow) control point for which flows are to be computed
- N gaged (known flow) control point from which flows are to be computed
- DA(cp) total drainage area on *WP* records above control point *cp*
- DAGAGE(N) incremental drainage area above the downstream gage and below the upstream gages
- DAUG(I) incremental drainage area between the ungaged site and upstream gages
- Q(cp) total flows on *IN* records at control point *cp*
- QGAGE(N) incremental local flows at the downstream gage from which QUG(I) are computed
- QUG(I) incremental local flows at the ungaged site computed as a function of QGAGE(N)

$$DAUG(I) = DA(I) - DA(J) - DA(K)$$

$$DAGAGE(N) = DA(N) - DA(J) - DA(K) - DA(L) - DA(M)$$

$$QGAGE(N) = Q(N) - Q(J) - Q(K) - Q(L) - Q(M)$$

$$Q(I) = QUG(I) + Q(J) + Q(K)$$

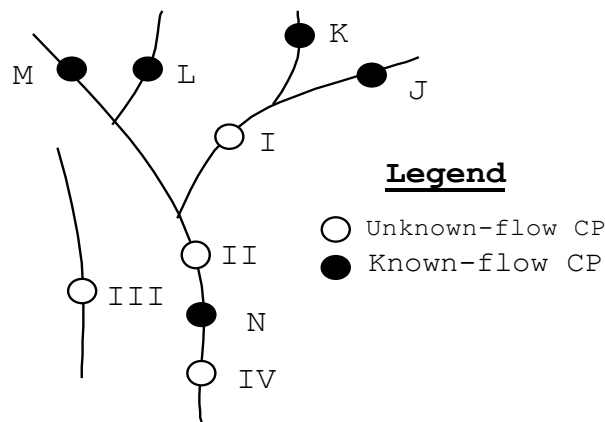


Figure 3.1 Gaged (Known-Flow) and Ungaged (Unknown-Flow) Control Points in Example 4 of Appendix C

For each ungaged control point, there is one gaged (known-flow) control point from which flows are transferred. Other gaged control points located upstream may be used to define the local

incremental watersheds for both the gaged source CP and the ungaged CP. The following information is provided on the flow distribution *FD* record of the control point for which flows are being generated.

- control point identifier of ungaged (unknown-flow) control point to which flows are being distributed (*ID* in *FD* record field 2)
- control point identifier of gaged (known-flow) control point from which flows are being distributed (*DSG* in *FD* record field 3)
- control point identifiers of the upstream control points used to compute incremental flows for the source control point (*UGID(I), I=1, MAXGAG* on *FD* record)
- the number of upstream control points used to compute the incremental flows at the ungaged (unknown-flow) control point (*NG* in *FD* record field 4)

The gaged control point from which flows are computed is called the source CP. As illustrated by Fig. 3.1, the ungaged site may be either upstream of the source CP, downstream of the source CP, or on a different tributary. Any of the upstream control points may also be used to define the incremental watershed above the ungaged CP. The variable *NG* on the *FD* record indicates how many of the gaged CPs above the source CP are also located above the ungaged site. For example, the flows at CP I in Fig. 3.1 may be determined from the flows at source CP N. Upstream CPs K, J, M, and L are listed on the *FD* record to define an incremental watershed for source CP N. *NG* is 2, indicating that the first two upstream CPs listed (CPs K and J) define the incremental watershed above ungaged CP I. *NG* is 4 for transferring incremental flows below J-K-L-M from N to II. *NG* is zero for computing flows at control point III from either total or incremental flows at control point N. For simplicity, the flow equations are shown in Fig. 3.1 without channel loss adjustments.

A *NG* of -1 on a *FD* record indicates that flows at an ungaged site are computed from flows at a source control point located upstream. For example, referring to Fig. 3.1, for $NGAGE(IV) = -1$, the incremental flow at IV [*QUG(IV)*] is computed as a function of incremental or total flow at N [*QGAGE(N)*] and added to the total flow at N [*Q(N)*] to obtain the total flow at IV [*Q(IV)*], where:

$$\begin{aligned} DAUG(IV) &= DA(IV) - DA(N) \\ Q(IV) &= QUG(IV) + Q(N) \end{aligned}$$

As noted previously, if *INWS(cp)* on the *CP* record is blank or zero, the parameters on the *WP* record are for the total watershed above the gaged CP, and the parameters for the incremental watershed are computed using the other control points. A positive integer for *INWS(cp)* indicates that the watershed parameters on the *WP* record correspond to the incremental watersheds. In this case [*INWS(cp)* > 0], caution must be exercised to assure that incremental flows correspond to precisely the same control points as the incremental watersheds.

Flow Distribution Methods

Methods for distributing naturalized stream flows from gaged or known-flow locations to ungaged sites were explored early in the development of WRAP [29]. The same flow synthesis methods in both *HYD* and *SIM* are activated by option selection parameter *INMETHOD(cp)* in *CP* record field 6 and are based on parameters provided on *FD*, *FC*, and *WP* records in a DIS file.

Option 10 is based on Equation 3.23 and is applied only to total flows. The flow distribution methods listed as options 3 through 8 in Table 3.1 may be applied to either total or incremental flows as defined by *FD* records and are based on either:

- the drainage area ratio R_{DA} $Q_{ungaged} = R_{DA} Q_{gaged}$ (3.9)

- the regression equation $Q_{ungaged} = a Q_{gaged}^b + c$ (3.10)

with the coefficients a , b , and c input on a *FC* record. With default values of 1.0 and 0.0 for b and c and $a=R_{DA}$, this equation reduces to the drainage area ratio (R_{DA}) method.

- adaptation of the NRCS curve number method (Eqs. 3.16 & 3.17) with values for watershed parameters provided on *WP* records. If the watershed parameters (curve number and mean precipitation) are the same for both the gaged and ungaged watershed (or left blank on *WP* record), the modified NRCS CN method also reduces to the drainage area ratio method.
- the following equation which incorporates a channel loss coefficient F_{CL} into the drainage area ratio (R_{DA}) method.

$$Q_{ungaged} = Q_{gaged} \left(\frac{R_{DA}}{1 - R_{DA} F_{CL}} \right) \quad (3.11)$$

Multipliers and Control Point Identifiers on CP Records (Option 2)

HYD and *SIM* control point *CP* records include the variables $CPIN(cp)$ and $CPEV(cp)$ which specify other control points with flows or net evaporation-precipitation rates, respectively, which are to be used for control point cp . Thus, the flow at another control point can be used without change or multiplied by $CPDT(cp,1)$. The approach is referred to as option 2 in Table 3.1. Also, zero flows can be specified on the *CP* record.

Multipliers $CPDT(cp,1)$ and $CPDT(cp,2)$ are also input on the *CP* record. The naturalized flows and net precipitation-evaporation rates are multiplied by these factors. $CPDT(cp,1)$ and $CPDT(cp,2)$ are typically used for unit conversion factors. The flow multiplier $CPDT(cp,1)$ can also include a drainage area ratio or other flow distribution parameter. This provides another convenient alternative means for applying the drainage area ratio method for distributing flow. The approach is applicable only for total flows, not for incremental flows.

Generalized Regression Equation (Option 3)

Option 3 listed in Table 3.1 consists of distributing flows using Equation 3.10 with the coefficients a , b , and c input on a *FC* record.

$$Q_{ungaged} = a (Q_{gaged})^b + c$$

Various methodologies may be devised for developing the input parameters a , b , and c . For example, the coefficients could be developed from a regression analysis of the results of a watershed precipitation-runoff model [29].

With default values of 1.0 and 0.0 for b and c , the parameter a may be treated as a ratio of watershed parameters.

$$Q_{\text{ungaged}} = a Q_{\text{gage}} \quad (3.12)$$

where a is estimated from characteristics of the gaged and ungaged watersheds. The most common approach is to simply use the drainage area ratio:

$$a = R_{DA} = \frac{A_{\text{ungaged}}}{A_{\text{gage}}} \quad (3.13)$$

Alternatively, ratios for other watershed parameters could also be used. For example, the factor a in Equation 3.12 may be expressed as a function of mean precipitation M , curve number CN , and other parameters, as well as drainage area A .

$$a = \left(\frac{A_{\text{ungaged}}}{A_{\text{gage}}} \right)^{N_1} \left(\frac{M_{\text{ungaged}}}{M_{\text{gage}}} \right)^{N_2} \left(\frac{CN_{\text{ungaged}}}{CN_{\text{gage}}} \right)^{N_3} \left(\frac{\text{Other}_{\text{ungaged}}}{\text{Other}_{\text{gage}}} \right)^{N_4} \quad (3.14)$$

If all the exponents N_i are assumed to be unity, the constant C would be related to the watershed characteristics as

$$a = \left(\frac{A_{\text{ungaged}}}{A_{\text{gage}}} \right) \left(\frac{M_{\text{ungaged}}}{M_{\text{gage}}} \right) \left(\frac{CN_{\text{ungaged}}}{CN_{\text{gage}}} \right) \left(\frac{\text{Other}_{\text{ungaged}}}{\text{Other}_{\text{gage}}} \right) \quad (3.15)$$

Modified Curve Number Method (Options 4, 5, and 8)

Options 4 and 5 consist of applying an adaptation of the Natural Resource Conservation Service (NRCS) curve number (CN) method. It is possible, though not usual, for the modified NRCS CN method to result in higher flows at an ungaged upstream control point than at the downstream gaged control point from which flows are distributed. The only difference between options 4 and 5 is whether or not a constraint is added to prevent this from ever happening. With option 4, if the flow at the ungaged site computed with the CN method is greater than the flow at the gaged control point, the flow at the ungaged (unknown-flow) control point is set equal to the flow at the gaged (known-flow) control point. Option 5 does not impose this constraint.

As discussed later, inclusion of channel losses complicates the distribution of flows from a gage located downstream of the ungaged site. Option 8 was developed specifically for this situation. Option 8 is similar to option 5 except an iterative algorithm is adopted that allows incorporation of channel losses between an upstream ungaged control point and the gaged site located downstream from which flows are being distributed.

If the curve number and mean precipitation are the same for both the gaged and ungaged watersheds, the modified NRCS CN method reduces to the drainage area ratio method. The drainage area ratio method also becomes the default if both fields 4 and 5 of the *WP* record (curve number and mean precipitation fields) are blank or zero for one or both of the watersheds.

The Natural Resource Conservation Service (NRCS) relationship is as follows.

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \quad \text{if } P \geq 0.2S \quad (3.16)$$

$$Q = 0 \quad \text{if } P < 0.2S$$

$$S = \frac{1,000}{CN} - 10$$

where Q denotes runoff volume-equivalent in inches, P is precipitation depth in inches, S is the maximum potential retention, and CN is the curve number [29]. S represents the losses that would occur after initial abstractions are satisfied given unlimited rainfall. S is related to the watershed parameter CN which varies with soil type, land use, and antecedent precipitation.

The modified version of the NRCS CN method adapted to distributing monthly flows is described as follows. P is computed for the gaged watershed using Equation 3.16, given the naturalized flow Q and the CN for the gaged watershed. This P is multiplied by the ratio of mean precipitation ($M_{\text{ungaged}}/M_{\text{gage}}$) and substituted back into Equation 3.16 with the appropriate CN to determine Q for the ungaged site. Thus, the algorithm consists of the following computational steps performed for each month.

- Step 1:* The flow at the gage is divided by the drainage area A_{gage} and multiplied by a unit conversion factor to convert to an equivalent depth Q_{gage} in inches.
- Step 2:* Q_{gage} is input to the curve number equation (Equation 3.16) to obtain P_{gage} in inches. An iterative method is required to solve Equation 3.16 for P . This approximation for precipitation depth is assumed to be applicable to the ungaged subwatershed as well as the gaged watershed. Base flow is being distributed along with storm runoff, all in the same proportion.
- Step 3:* If the long-term mean precipitation varies between the watershed and subwatershed, the precipitation depth may be adjusted by multiplying P_{gage} by the ratio of the long-term mean precipitation depth of the subwatershed to that of the watershed to obtain a P_{ungaged} adjusted in proportion to mean precipitation.

$$\text{adjusted } P_{\text{ungaged}} = P_{\text{gage}} \left(\frac{M_{\text{ungaged}}}{M_{\text{gage}}} \right) \quad (3.17)$$

where M_{ungaged} and M_{gage} are the mean precipitation for the ungaged sub-watershed and gaged watershed. Otherwise, P_{ungaged} is assumed equal to P_{gage} .

- Step 4:* P_{ungaged} is input into Equation 3.16 to obtain Q_{ungaged} in inches. Q_{ungaged} in inches is multiplied by A_{ungaged} and a unit conversion factor to convert to flow.

Unit Conversion for NRCS CN Equation

The multiplier *DEPTHX* entered in *XL* record field 8 is used as a conversion factor if the default factor of 0.01875 is not adopted. The CN method uses runoff depth (stream flow volume) in inches computed as follows.

$$\text{Runoff depth in inches} = \left(\frac{\text{streamflow}}{\text{drainage area}} \right) \text{DEPTHX}$$

The default of $DEPTHX = 0.01875$ is defined as follows based on stream flow units of acre-feet/month and watershed drainage area units of square miles.

$$\text{Runoff depth in inches} = \left(\frac{\text{acre} \times \text{feet}}{\text{square mile}} \right) \left(\frac{43,560 \text{ ft}^3}{\text{acre} \times \text{foot}} \right) \left(\frac{\text{mile}}{5,280 \text{ ft}} \right)^2 \left(\frac{12 \text{ inches}}{\text{foot}} \right)$$

$$\text{Runoff depth in inches} = \left(\frac{\text{streamflow in acre} \times \text{feet}}{\text{drainage area in square miles}} \right) 0.01875$$

If units for stream flow other than acre-feet/month and/or drainage area units other than square miles are used, an appropriate $DEPTHX$ is entered on the XL record to convert the monthly runoff depth to inches. A conversion factor on the watershed parameter WP record allows converting units for watershed area. For example, for stream flow in thousand cubic meters ($1,000 \text{ m}^3$) and watershed area in square kilometers, $DEPTHX$ is 0.03937 determined as follows:

$$\text{Runoff depth in inches} = \left(\frac{1,000 \text{ m}^3}{\text{km}^2} \right) \left(\frac{\text{km}}{1,000 \text{ m}} \right)^2 \left(\frac{39.37 \text{ inches}}{\text{meter}} \right)$$

$$\text{Runoff depth in inches} = \left(\frac{\text{streamflow in } 1,000 \text{ m}^3}{\text{drainage area in km}^2} \right) 0.03937$$

The mean precipitation depth MP is used only to obtain ratios of MP_{ungaged} to MP_{gaged} . Thus, any depth unit may be used as long as the same unit is used for all watersheds.

Bounds on Curve Number (CN), Mean Precipitation (MP), and Flow

The SIM and HYD subroutine $FLDIST$ distributes flows from gaged to ungaged locations for options 3 through 8 listed in Table 3.1. Subroutine $IACNP$ reads the FD and WP records from the DIS file and computes incremental drainage areas (A), curve numbers (CN), and mean precipitation (MP) for use in subroutine $FLDIST$. The CN and MP for an incremental watershed are computed from the CN 's and MP 's read from the WP records for total watersheds. The basic premise in computing the CN and MP for an incremental watershed is that the CN or MP for a total watershed equals the area-weighted average of the values for all its subwatersheds.

Situations may occur in which the CN or MP input for total watersheds are unrealistically low or high. Unrealistic values may also result for the computed CN 's or MP 's for small incremental subwatersheds. Problems may be related to preciseness of the CN 's and MP 's relative to the size of incremental subwatersheds that are a very small portion of the total watershed. The CN may be negative or exceed 100, violating the definition of CN and resulting in negative flows from the CN method algorithm.

WRAP-SIM has an option for placing bounds on the curve numbers CN and mean precipitation MP used in synthesizing flows. If in determining flows for any particular ungaged control point, the CN or MP for either the gaged or ungaged incremental or total watershed falls outside the specified lower and upper bounds, the drainage area ratio method is used instead of the NRCS CN method. Under these conditions, *INMETHOD* options 4 and 5 revert to option 7 (drainage area ratio method without channel losses), and option 8 reverts to option 6 (with channel losses). Only flows at ungaged control points with watershed parameters violating the bounds are affected by this feature. This will likely affect only a very small portion, if any, of the control points in any particular river basin.

Warning messages are written to the message file for each control point total or incremental watershed for which either the CN or MP violates either the lower or upper bounds. Negative watershed areas are treated as errors that result in an error message and termination of program execution.

The default lower and upper bounds are zero and 100 for CN's. The default bounds are zero and 100 units (inches or other units) for MP's. Optionally, the bounds may be specified in the *XL* record.

Incremental flows at a gaged control point are computed in subroutine *FLDIST* by subtracting flows at upstream control points specified on a *FD* record. Incremental flows are used in distributing flows from gaged to ungaged control points. The incremental flows may be computed as negative numbers. Negative incremental flows are converted to zeros for all flow distribution options except option 8. Also, after the flow distribution computations, any negative total flows computed for ungaged control points are converted to zero, except for option 8. With option 8, negative incremental flows trigger reverting to option 6. Thus, for option 8, a negative incremental flow has the same effect as a CN or MP violating lower or upper bounds.

Incorporation of Channel Losses in Flow Distribution Options 3, 4, 5, 6, 7 and 8

Flow distribution is one of several aspects of a *WRAP* simulation for which channel losses may be pertinent. Channel losses are relevant for all of options 3-8, though handled differently by options 6 and 8. Channel losses are discussed earlier in this chapter. All of the channel loss routines in the model use a channel loss coefficient F_{CL} for the river reach below a control point, that is entered as variable $CL(cp)$ in the *CP* record. F_{CL} is defined by Equation 3.3.

The alternative flow distribution methods 3 through 8 listed in Table 3.1 may be applied to either local incremental subwatersheds or the total watersheds above the gaged and ungaged control points. If incremental stream flow is used, the unknown total flow at an ungaged control point is determined from the known flow at a gaged control point in three steps.

1. The incremental flow at the gage is computed by subtracting the total flow at the gage from the sum of flows at appropriate upstream gages adjusted to remove the effects of channel losses.
2. The incremental flows at the gage, computed in step (1), are distributed to the ungaged site using one of the optional methods described here.

3. The incremental flows at the ungaged site, computed in step (2), are added to the flows at appropriate upstream control points, adjusted for channel losses, to obtain the total flows at the ungaged site.

Channel losses are included in steps 1 and 3 for all of the flow distribution options as long as the F_{CL} for the pertinent reaches are non-zero. All of the flow distribution options may be applied concurrently with channel loss factors F_{CL} under appropriate circumstances in cases where the ungaged site is located downstream of the source control point or on a different tributary. However, options 6 and 8 are designed specifically to address the situation described below.

Ungaged Control Point Located Upstream of Source Gaged Control Point

Options 6 and 8 in Table 3.1 are designed to be applied specifically and only for the situation in which the ungaged control point is located upstream of the source gaged site with channel losses occurring in between. This situation is complicated by the fact that the flow at the ungaged site is a function of the flow at the gaged site Q_{gaged} plus channel losses $F_{CL}Q_{ungaged}$

$$Q_{ungaged} = f(Q_{gaged} + F_{CL}Q_{ungaged}) \quad (3.18)$$

and channel losses are a function of $Q_{ungaged}$ (loss = $F_{CL}Q_{ungaged}$). Thus, $Q_{ungaged}$ is on both sides of Equation 3.18.

This complexity in incorporating channel losses in the flow distribution algorithms is illustrated by referring to Figure 3.1 and assuming that flows at CP I and CP II are computed from either the total or incremental flow at CP N. If incremental flows at N are used, the channel losses in the reaches below M, L, K, J, I, and II are considered in computing the incremental flow at N. The complexity is that the channel loss in the reach below CP II depends upon the unknown flow at CP II. The flow at control point II is a function of flow at N plus channel losses.

$$Q_{II} = f(Q_N + F_{CL}Q_{II})$$

This function is expressed as follows for the drainage area ratio method.

$$Q_{II} = R_{DA} (Q_N + F_{CL}Q_{II})$$

Likewise, with flows being distributed from CP N to CP I, the channel losses in the reaches between I and II and between II and N depend upon the unknown flows at control points I and II. Thus, channel losses may occur in multiple reaches between the gaged and upstream ungaged sites. For multiple reaches in series, the total channel loss is determined by multiplying the flow at the most upstream control point by an equivalent N-reach F_{CL} determined by combining the channel losses F_{CLi} for each reach as follows:

$$\text{Equivalent } (1.0 - F_{CL}) = (1.0 - F_{CL1})(1.0 - F_{CL2})(1.0 - F_{CL3}) \dots (1.0 - F_{CLN}) \quad (3.19)$$

Options 6 and 8 are modifications of the drainage area ratio and NRCS CN methods to incorporate channel losses between an upstream ungaged (unknown flow) control point and a gaged (known flow) site located downstream from which flows are being distributed. Options 6 and 8 are applicable only in cases where:

- The ungaged site is located upstream of the source gaged control point.
- Channel losses occurring between the ungaged and gaged control points are significantly greater than otherwise captured by the CN or DA methods.

Options 6 and 8 incorporating the channel loss factor (F_{CL}) are applicable if the channel losses in the reach between the ungaged and gaged control point are significantly greater than in the other streams in the watershed and thus not adequately reflected in the flow proportioning of the CN and drainage area ratio methods without the F_{CL} . Incorporating a F_{CL} results in higher estimates of the flow amounts at the ungaged control point.

Drainage Area Ratio with Channel Losses (Option 6)

As noted above, the drainage ratio method may be expressed as

$$Q_{\text{ungaged}} = R_{DA} (Q_{\text{gaged}} + F_{CL}Q_{\text{ungaged}}) \quad (3.20)$$

for a situation with a ungaged control point located upstream of a gaged control point, with the channel losses occurring between the ungaged and gaged control point being significantly greater than reflected in proportioning flows based on the R_{DA} alone. R_{DA} is the drainage area ratio ($A_{\text{ungaged}}/A_{\text{gage}}$), and F_{CL} is the channel loss coefficient. Q_{ungaged} and Q_{gaged} denote the naturalized flow (either total or incremental) at the two control points. $(Q_{\text{gaged}} + F_{CL}Q_{\text{ungaged}})$ denotes the flow at the gage adjusted to remove the effect of channel losses in the reach between the ungaged and gaged sites. If intermediate control points are located between these locations, the F_{CL} is an equivalent multiple-reach channel loss factor determined as noted earlier. This equation is algebraically rearranged to obtain the previously noted Equation 3.11.

$$Q_{\text{ungaged}} = Q_{\text{gaged}} \left(\frac{R_{DA}}{1 - R_{DA} F_{CL}} \right) \quad (3.11)$$

INMETHOD(cp) option 6 in Table 3.1 consists of applying Equation 3.11. The model obtains F_{CL} from the *CP* record for the ungaged control point and the watershed areas from the appropriate *WP* records. For multiple intermediate control points between the gaged and ungaged sites, an equivalent F_{CL} is determined as previously noted. Option 6 is applicable only in situations where the ungaged control point is located upstream of the gaged control point and the channel losses between the control points are greater than otherwise reflected in the simple drainage area ratio method of Equation 3.9.

NRCS CN Method with Channel Losses (Option 8)

Referring to Figure 3.1, options 4 and 5 applying the NRCS CN method is applicable for transferring flow from source control point N to either control points III or IV. Options 4 and 5 are applicable in the situation of the ungaged CP being located above the gaged control point, such as in transferring flows from control point N to control points I and II, if channel loss factors for control point I and control point II are zero. Option 8 is pertinent in situations in which the ungaged site is located upstream of the gaged site with channel losses occurring in between that are greater than otherwise reflected in options 4 and 5.

Option 8 is pertinent only in situations in which the ungaged site is located upstream of the gaged site with channel losses occurring in between. Option 8 consists of combining Equations 3.21 and 3.22

$$Q_{\text{ungaged}} = f(Q_{\text{gaged}} + F_{\text{CL}}Q_{\text{ungaged}}) \quad (3.21)$$

$$\text{Equivalent } (1.0 - F_{\text{CL}}) = (1.0 - F_{\text{CL1}}) (1.0 - F_{\text{CL2}}) (1.0 - F_{\text{CL3}}) \dots (1.0 - F_{\text{CLN}}) \quad (3.22)$$

with the NRCS CN method. If the known flow Q_{gaged} is zero, then the unknown flow Q_{ungaged} is set equal to zero. Otherwise, the following iterative algorithm is employed.

1. For the initial iteration, the channel loss $F_{\text{CL}}Q_{\text{ungaged}}$ is set equal to zero, and thus $(Q_{\text{gaged}} + F_{\text{CL}}Q_{\text{ungaged}})$ is set equal to Q_{gaged} .
2. The CN method based on Equations 3.16 and 3.17 is applied following the steps previously outlined identically as with option 5 to compute an intermediate value for Q_{ungaged} for the given $(Q_{\text{gaged}} + F_{\text{CL}}Q_{\text{ungaged}})$ from steps 1 and 3.
3. Given the Q_{ungaged} computed in step 2 above, $F_{\text{CL}}Q_{\text{ungaged}}$ and thus $(Q_{\text{gaged}} + F_{\text{CL}}Q_{\text{ungaged}})$ are determined.

Steps 2 and 3 are repeated iteratively until a stop criterion is met. The stop criterion is that the change in successive values of Q_{ungaged} is less than 0.5 percent. The algorithm is terminated after 100 iterations and a warning message is recorded in the message file.

Secondary CP Flows Computed from Flows at Multiple Source Control Points (Option 10)

INMETHOD(cp) option 10 determines flows at an ungaged site based on weighting flows at any number NG of primary control points (gages) using the following equation.

$$Q_{\text{ungaged}} = C_1 [C_4Q_1 + C_5Q_2 + C_6Q_3 + \dots C_{\text{NG}+3}Q_{\text{NG}}]^{C_2} + C_3 \quad (3.23)$$

$Q_1, Q_2, Q_3, \dots, Q_{\text{NG}}$ are the total (not incremental subwatershed) naturalized flows at the gaged primary control points specified on the *FD* record. $C_1, C_2,$ and $C_3, \dots, C_{\text{NG}+3}$ are coefficients entered on a *FC* record. The multiplier factor C_1 , exponent C_2 , and addition factor C_3 in Eq. 3.23 have *FC* record defaults of 1.0, 1.0, and 0.0.

With option 10, the flows $Q_1, Q_2, Q_3, \dots, Q_{\text{NG}}$ at NG source (gaged or known-flow) control points are combined to compute the flow at the secondary (ungaged or unknown-flow) control point. Multiple upstream control points may be listed on the *FD* record for *CP* record *INMETHOD(cp)* options 3 through 8 to define incremental subwatersheds and incremental flows, but only one source control point can be specified. However, the flows Q_{CP} in Equation 3.23 are total, not incremental, flows. Any number NG of source control points may be used. The alternative flow distribution methods are compared in Example 4 of Appendix C.

The flow coefficient *FC* record is used alternatively to enter the coefficients $a, b,$ and c for Equation 3.10 or the coefficients $C_1, C_2, \dots, C_{\text{NG}+3}$ for Equation 3.23. Thus, the definition of the coefficients provided on *FC* records varies depending on whether *INMETHOD(cp)* option 3 or option 10 is specified on the *CP* record for a particular control point.

The Equation 3.23 coefficients $C_1, C_2, C_3, \dots, C_{NG+3}$ may be either positive or negative numbers. The coefficients may represent drainage area ratios or other parameters. If naturalized flows are known at all pertinent control points for a portion of the period-of-analysis or some period of time, the coefficients may be determined as ratios of mean flows. Choices of control points and positive and negative coefficients are based upon the ingenuity and judgment of the model-user and will vary with different river system control point configurations.

Control Point Ordering and Allowable Source Control Points

Primary control points are defined as locations at which flows are entered in a *SIM* input dataset as *IN* records in a FLO file or DSS records in a DSS file. Secondary control points are sites for which flows are computed within the *SIM* or *HYD* programs based upon flows entered for one or more other control points, called source control points, using the methods listed in Table 3.1. The flows read from an input file for all primary control points as step 1 listed below may be used in computing flows at any of the secondary control points. Source control points are typically primary control points but can also be secondary control points under certain conditions outlined as follows.

Naturalized flows are established for each individual control point based on the *INMETHOD(cp)* option selected on its *CP* record. The options are listed in Table 3.1. For a particular year and month of the *SIM* simulation or *HYD* application, naturalized flows are assigned to control points in the following sequential order.

- Step 1.- Flows are read from *IN* or DSS records for all primary control points in the sequential order in which the *CP* records are entered in the DAT file (*INMETHOD(cp)* option 1).
- Step 2.- Flows may be transferred from primary control points to secondary control points based on the parameters *CPIN(cp)* and *CPDT(cp,1)* from the *CP* record (option 2). All secondary control points are considered in the sequential order of the *CP* records.
- Step 3.- *INMETHOD(cp)* option 10 is activated as secondary control points are again considered in the sequential order in which the *CP* records are entered in the DAT file. Option 10 deals only with total flows, not incremental flows.
- Step 4.- *INMETHOD(cp)* options 3 through 8 are activated as secondary control points are once again processed through a control point loop in the sequential order of the *CP* records. An incremental flow computational loop for all control points is followed by another loop that computes total flows. Source control points must have been assigned flows in the preceding Steps 1, 2, or 3.
- Step 5 - The *INMETHOD(cp)* option 2 routine applied in Step 2 is repeated to allow secondary control points to also serve as source control points for option 2. Step 5 allows secondary control points with flows computed in steps 2, 3, or 4 to serve as source control points for option 2.

Option 2 secondary control points with flows assigned in step 2 can serve as source control points for any of the other options 3, 4, 5, 6, 7, 8, and 10 secondary control points with flows assigned in the subsequent steps 3 and 4. Due to step 5, secondary control points deriving flows from any option can also serve as sources for option 2 control points.

The *INMETHOD(cp)* option 10 control points with flows assigned in step 3 can also serve as source control points for any of the options 3 through 8 control points with flows assigned in step 4. Option 10 control points can serve as flow transfer sources for other option 10 control points as long as the *CP* record of the source control point is entered in the DAT file ahead of the *CP* record of the control point for which flows are computed.

Control points with flows assigned in step 4 with *INMETHOD(cp)* options 3 through 8 should not be specified on *FD* records as serving as any type of source control points. Warning messages are written to the message file in most cases when source control points specified on a *FD* record are not valid based on the rules outlined above. However, these are warning messages rather than an error message, meaning that program execution is not terminated.

Watershed Flow Option

WRAP-SIM includes an alternative simplified option for dealing with water right diversions and storage at many remote ungaged locations throughout the watersheds above the control points. The watershed flow option supplements the control point network in delineating the location of water rights. All rights are assigned a control point and, in the model computations, affect unappropriated flows and water availability at that control point and downstream control points. Multiple rights may be assigned to the same control point. The watershed flow option is used for rights at locations in the watersheds above their assigned control points. The site in the watershed at which the right is actually located has no *CP* record and is not treated as a control point. *SIM* limits water available to each of these rights to the lesser of:

- naturalized stream flows at the site
- yet unappropriated flows at the control point assigned to the right and downstream control points.

The naturalized stream flows at the watershed sites are determined by multiplying the naturalized stream flows at the control point by a user-specified factor. The drainage area ratio or other flow multiplier for a water right is provided as variable *WSHED(wr)* on the *SO* record.

Use of GIS to Determine Spatial Connectivity and Watershed Parameters

The usefulness of a geographic information system (GIS) in developing input data for WRAP depends largely on the number of control points incorporated in the model and the methodology adopted for transferring naturalized stream flows from gaged to ungaged locations. Development of the Texas WAM System involved thousands of control points and parameters for thousands of subwatersheds for distributing naturalized flows. Thus, a GIS was essential.

Locations are defined based on control points. The *CP* record for each control point includes the identifier of the next downstream control point. The computational routines within WRAP use the designated next downstream control points to define spatial connectivity. Watershed drainage areas are required for all of the methods for distributing naturalized flows from gaged to ungaged sites. The curve number and mean precipitation are also required if the NRCS CN method adaptation is used for distributing flows. For river basins with numerous control points, GIS is very useful for developing these spatially oriented components of the input datasets.

Negative Incremental Naturalized Stream Flows

SIM naturalized stream flow input, computational algorithms, computed regulated and unappropriated flows, and associated variables are all based on total flows, rather than incremental flows. Although incremental watersheds and incremental flows may be used in distributing flows from gaged to ungaged locations, the final synthesized flows used in the simulation are total flows. Thus, a simulation is based on cumulative total stream flows, not incremental inflows. However, situations in which naturalized flows at a particular control point are less than concurrent flows at upstream locations are described in terms of negative incremental inflows. The relevance of negative incremental flows and options for dealing with them are addressed in this section.

The incremental inflow between a control point and other control point(s) located upstream is the naturalized flow at the downstream location minus the concurrent flow at the upstream location(s). Since stream flow usually increases going downstream, incremental inflows are typically positive. However, situations with flows at upstream locations exceeding concurrent flows at a downstream location are not unusual. Negative incrementals for actual observed stream flows at gaging stations may result from: channel seepage and evapotranspiration losses; recorded or unrecorded diversions; large travel times causing the effects of precipitation events to reach adjacent control points in different time periods; and/or measuring inaccuracies or data recording errors. Computational adjustments to convert gaged flows to naturalized flows introduce other inaccuracies that may contribute to incremental naturalized stream inflows being negative.

ADJINC Options for Dealing with Negative Incremental Naturalized Stream Flows

Programs *HYD* and *SIM* include options, specified by variable *ADJINC* on the *JC* or *JD* record, to deal with negative incremental inflows. Options 1, 2, and 3 are incorporated in both *HYD* and *SIM*. The other *ADJINC* options listed below are relevant only to *SIM*.

- Option 1:* All downstream control points are considered in determining flow availability for each water right, and there are no negative incremental flow adjustments.
- Option 2:* Downstream negative incremental flow adjustments are applied at all control points at the beginning of the simulation.
- Option 3:* Upstream negative incremental flow adjustments are applied at all control points at the beginning of the simulation.
- Option -3:* Variation of option 3 in which incremental flow adjustments are applied only at primary control points, not control points with synthesized flows.
- Option 4:* As flow availability is determined for each water right at each time step during the simulation, upstream negative incremental flow adjustments are applied at the downstream control points but not at the control point of the right.
- Option -4:* Variation of option 4 in which incremental flow adjustments are applied only at primary control points, not control points with synthesized flows.
- Option 5:* The simulation algorithms are modified as discussed later for option 5. Whereas options 2, 3, and 4 involve computation of an array of flow adjustments, there are no negative incremental flow adjustments with option 5.

- Option 6: Option 6 is same as option 4 except the downstream control points used in determining flow availability are limited to sites of senior rights. Simulation results are identical with either option 4 or 6 but execution time is reduced with option 6.
- Option 7: Option 7 is the same as option 1 except the downstream control points used in selecting the minimum flow are limited to sites of relevant senior rights.
- Option 8: Option 8 ignores all downstream control points. The flow at the control point of the water right is assumed to be the flow available to the water right.

Negative incremental flow *ADJINC* options 1, 2, 3, -3, 4, -4, and 5 date back to early versions of WRAP. *ADJINC* options 6, 7, and 8 were added in early 2011. Option 4 has been the recommended standard. The new option 6 yields identically the same simulation results as option 4, but the computer runtime is reduced. Thus, option 6 replaces option 4 as the standard though reducing *SIM* execution time is not a major concern in most monthly simulation applications. Option 5 has also been applied extensively with the TCEQ WAM System. Option 7 is recommended whenever routing is adopted in *SIMD* daily simulations. Option 7 was created for *SIMD* daily simulations but can also be applied in *SIM* monthly simulations.

Options 1, 2, -3, 3, -4, and 8 are generally not good options for use in actual assessments of water availability. However, these *ADJINC* options provide opportunities for experimentation in simulation studies. Alternative simulations with these options provide insight on the effects of various premises on simulation results.

The remainder of this chapter is a discussion of the negative incremental flow options. Chapter 7 of TWRI TR-389 (Wurbs *et al.* 2011) is a case study comparative evaluation of the alternative *ADJINC* options.

NEGINC Options for Recording Information in the Message File

NEGINC options do not affect simulation results but rather print selected information in the message file which the user can examine to determine the extent of the negative incrementals. *NEGINC* options 1, 2, and 3 activated on the *SIM JD* record and *HYD JC* record date back to early versions of WRAP. Options 4 and 5 were added to *SIM* in early 2011.

- Option 1 is the default of recording no negative incremental information in the message file.
- Option 2 writes all negative incremental flows defined looking downstream for all months at all control points. The *downstream* negative incremental flow for a control point is the greatest negative difference between the naturalized flow at the control point and any other control point located downstream.
- Option 3 writes all negative incremental flows defined looking upstream for all months at all control points. The upstream flow adjustments are defined as the minimum additional monthly volume that must be added at each control point to remove all negative incrementals in the set of all naturalized flows at all control points.
- Option 4 provides just a summary table.
- Option 5 lists all control points that have one or more negative incremental flows along with the number of negative incremental flows as well as the option 4 summary table.

Example 3 - Negative Incremental Stream flows

An example is provided in Figure 3.2 and Tables 3.2 and 3.3. Naturalized flows at each control point for a particular month are tabulated in column 2 of Table 3.2 and also shown in the figure. The incremental inflows between each control point and its adjacent upstream control points are shown in column 3. Incremental flows are negative at control point CP-2 (incremental flow = $81 - 90 = -9$) and control point 6 (incremental flow = $80 - 100 - 8 = -28$). As illustrated by columns 4 and 6 of Table 3.2 and discussed later, negative incremental flows alternatively may be defined considering all control points located either upstream or downstream of a particular control point. As illustrated by columns 5 and 7 of Table 3.3 and also discussed later, negative incremental flows may be eliminated by adjusting the flows at pertinent control points. Table 3.3 shows the amount of naturalized stream flow available for the most senior right for each of the *ADJINC* options.

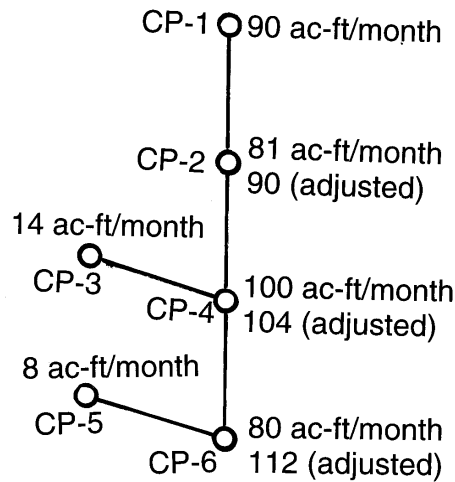


Figure 3.2 System with Negative Incremental Inflows

Table 3.2
Total and Incremental Naturalized Stream Flows for Example 3

1	2	3	4	5	6	7
Control Point	Naturalized Total Flow (ac-ft/month)	Adjacent CP Incremental Flow (ac-ft/month)	Downstream Negative Incremental (ac-ft/month)	Adjusted Total Flow (ac-ft/month)	Upstream Negative Incremental (ac-ft/month)	Adjusted Total Flow (ac-ft/month)
CP-1	90	90	-10	80	0	90
CP-2	81	-9	-1	80	9	90
CP-3	14	14	0	14	0	14
CP-4	100	5	-20	80	4	104
CP-5	8	8	0	8	0	8
CP-6	80	-28	0	80	32	112

Table 3.3
Available Stream Flows at the Beginning of the Simulation

1	2	3	4	5	6	7
Control Point	Naturalized Total Flow (ac-ft/month)	$CL(I)=0.1$ $CL(4)=0.2$ Avail Flow (ac-ft/month)	Option 1 Available Flow (ac-ft/month)	Option 2 Available Flow (ac-ft/month)	Option 3 Available Flow (ac-ft/month)	Options 4-8 Available Flow (ac-ft/month)
CP-1	90	90	80	80	90	90
CP-2	81	81	80	80	90	81
CP-3	14	14	14	14	14	14
CP-4	100	100	80	80	104	100
CP-5	8	8	8	8	8	8
CP-6	80	80	80	80	112	80

The amount of naturalized stream flow available at the beginning of the simulation for the current month in Example 3 is shown in Table 3.3 for each of the *ADJINC* options. These amounts represent the stream flow available to the most senior right if it is located at each of the control points. The available flows for the month at the different control points at the beginning of the priority-sequenced water rights simulation are the same for *ADJINC* options 4, 5, 6, 7, and 8. However, stream flow availability may differ with these alternative *ADJINC* options activated as the simulation progresses through the water rights priority sequence.

The available flows for *ADJINC* option 1 with and without the optional *CP* record channel loss factors are tabulated in columns 3 and 4, respectively, of Table 3.3. The available flows in column 3 are based on combining the default (option 1) no incremental flow adjustments with channel loss computations with loss factors $CL(cp)$ of 0.1 and 0.2 for control points CP-1 and CP-4, respectively. Although not shown in the table, combining the channel loss factors $CL(I)=0.1$ and $CL(4)=0.2$ with option 4 results in the same available flows shown in both columns 3 and 7. Option 2 consists of adding the adjustments from column 4 of Table 3.2 to obtain the available stream flow shown in column 5 of Table 3.3. Options 3 and 4 both involve computation of the flow adjustments in column 6 of Table 3.2, but the adjustments are applied differently with option 4 than with option 3. Options 6 and 7 are the same as option 1 and 4, respectively, but consider only those downstream control points at which are located water rights that are senior to the current right.

Significance of Negative Incremental Naturalized Stream Flows

The *WRAP-SIM* simulation progresses through each monthly computational time step with each water right considered sequentially in priority order. Stream flow depletions and return flows associated with a water right affect stream flows at the control point of the water right and at control points located downstream. The simulation computations determine the amount of stream flow available to each water right in each month of the simulation as the lesser of the available stream flow at the control point of the water right and at downstream control points. Flows may be less at downstream control points due to two factors: (1) the effects of senior water rights in depleting flows and (2) negative incremental naturalized stream flows.

The relevance of flows being smaller downstream than upstream (negative incremental) is due to the effects on the amount of stream flow available to water rights and the unappropriated flows in the *WRAP-SIM* simulation. Within the water rights loop, for a given month, the amount of stream flow available to a water right is computed as the lesser of the yet unappropriated (considering all higher seniority rights) stream flows at the control point of the right and at downstream control points. The computational loop begins with naturalized stream flows. Thus, in the *WRAP-SIM* simulation, negative incremental inflows at downstream locations may reduce the stream flow available at upstream control points. The reduction in water availability may or may not be appropriate, depending on the actual cause of the negative inflows.

Referring to Figure 3.2 and column 4 (option 1: no adjustments) of Table 3.3, the amount of stream flow initially available at control point CP-1 is the lesser of the total stream flows at CP-1 (90 ac-ft), CP-2 (81 ac-ft), CP-4 (100 ac-ft), or CP-6 (80 ac-ft). Thus, the available flow at CP-1 is 80 ac-ft, which is governed by the CP-6 flow that reflects negative incremental flow. The available flow at CP-4 is 80 ac-ft. As the water rights computational loop progresses, the amount of water availability to rights at each control point may be further reduced by senior rights.

The impacts of negative incremental inflows in the computations may or may not properly represent the actual situation being modeled. Difficulty in determining the actual combination of factors contributing to incremental naturalized flows being negative represents a major complexity in deciding how to deal with them. Negative incremental flows may occur in multiple months at multiple control points. The reasons for the negative incremental flows may vary between months and between locations. A rainfall event centered over the watershed above a particular stream gaging station, occurring near the end of a month, may contribute much runoff to that gage that month, but the runoff does not reach the next downstream gage until early in the next month. At other times of the year, negative incremental flows in this river reach may be caused primarily by unrecorded diversions for farming operations. In some cases, the negative incremental flows may be related primarily to channel losses due to seepage and/or evapotranspiration. Measurement and computation inaccuracies and peculiarities in *SIM* input datasets add to the complexities of explaining the cause of negative incrementals.

The same phenomena that cause incremental inflows to be negative are also reflected in fluctuations in positive incremental flows. Modeling uncertainties associated with negative incremental inflows are inherent in the model even if all incrementals are positive. The peculiarities of negative incrementals are simply more evident.

Channel Losses

Channel loss factors $CL(cp)$ entered on the control point *CP* records in the *SIM* input DAT file are defined by Equation 3.3. $CL(cp)$ are used in the various channel loss computations that occur throughout the *SIM* simulation. Conceptually, if the negative incremental flows are due strictly to channel losses, and if the linear channel loss equation (Eq. 3.3) accurately models channel losses, negative incrementals are handled automatically within *SIM* and are not a concern. Of course, in reality, negative incrementals can not be perfectly explained with a simple linear relationship between channel loss and upstream flow. However, the channel loss routine incorporated in determining the amount of water available for a right may significantly reduce or mitigate the effects of negative incremental flows. The term *excess negative incremental flow* is adopted here to refer to the portion

of a negative incremental flow not accounted for by the channel loss factor and associated *SIM* channel loss computations.

In Example 3 (Figure 3.2), if $CL(cp)$ for control points CP-1 and CP-4 are 0.1 and 0.2, respectively, or greater, the negative incremental flows do not constrain water availability at upstream locations at the beginning of the simulation. The amount of water available at control point CP-4 for the first water right in the priority sequence is 100 acre-feet as shown in column 3 of Table 3.3. The 100 acre-feet of available stream flow at control point CP-4 is determined as the minimum of:

$$\text{CP-4: } 100$$

$$\text{CP-6: } 100 = 80 / (1.0 - CL(4)) = 80 / (1.0 - 0.2)$$

The 90 acre-feet at control point CP-1 is determined as the minimum of the following values.

$$\text{CP-1: } 90$$

$$\text{CP-2: } 90 = 81 / (1.0 - CL(1)) = 81 / (1.0 - 0.1)$$

$$\text{CP-4: } 111 = 100 / [1.0(1.0 - CL(1))] = 100 / [1.0(1.0 - 0.1)]$$

$$\text{CP-6: } 111 = 80 / [(1.0 - CL(4))(1.0)(1.0 - CL(1))] = 80 / [(1.0 - 0.2)(1.0)(1.0 - 0.1)]$$

Downstream versus Upstream Negative Incremental Flow Adjustments

HYD and *SIM* negative incremental flow adjustment options are based on two alternative ways of defining negative incremental flow adjustments, referred to as *downstream* versus *upstream* incrementals. The approach for computing the *downstream* incremental flow adjustments associated with a particular control point compares its flow to the flow at each control point located downstream. Negative incremental flows between a control point and its downstream control points are shown in column 4 of Table 3.2. The negative incremental inflow is the greatest difference between the naturalized stream flow at the control point and any control point located downstream. The negative incremental flow is written as either zero or a negative number indicating the amount that must be subtracted from the flow at that control point to equal the lowest flow occurring at any downstream control point. These downstream negative incremental flow adjustments are added to the naturalized flows in column 2 to obtain the adjusted flows in column 5 of Table 3.2.

Upstream negative incremental flow adjustments associated with a control point represent the amount that must be added to the flow at that control point to remove all negative incremental flows occurring at all control points located upstream. This form of negative incremental flow is written to the *HYD* OUT or *SIM* MSS files as either zero or positive, indicating an amount the stream flow at the control point must be increased to alleviate negative incrementals. Upstream negative incremental flow adjustments for the example are shown in column 6 of Table 3.2. These adjustments are added to the naturalized flows to obtain the adjusted flows in column 7.

ADJINC option 2 is based on downstream negative incremental flow adjustments as defined above. *ADJINC* options 3, 4, and 6 are based on upstream negative incremental flow adjustments. The other *ADJINC* options do not develop negative incremental flow adjustments.

Description of ADJINC Options for Dealing with Negative Incrementals

Option 1 consists of considering all downstream control points and applying no flow adjustments in determining the amount of stream flow available to each water right. Water rights are subject to being penalized for negative incremental naturalized flows at any downstream control points regardless of whether senior water rights are located there. Option 1 places maximum restrictions on the amount of stream flow available to the water rights. Use of the channel loss option reduces or eliminates the restrictions on water availability associated with negative incremental flows. If the negative incremental flows are due primarily to channel losses and reasonably good values for $CL(cp)$ are available, option 1 may be reasonably accurate.

Options 2 and 3 replicate older practices predating WRAP in which naturalized flows are adjusted to remove negative incrementals prior to inputting them to a simulation model. Modelers have in the past adjusted naturalized flows to remove negative incrementals in the process of compiling input datasets for *WRAP-SIM* or other models. Options 2 and 3 perform the flow adjustment computations at the beginning of the *SIM* execution in conceptually the same manner as traditional methods for adjusting the naturalized flows outside of the model.

Option 2 is based on downstream negative incremental flow adjustments. Since control points on multiple tributaries are not considered concurrently, there is no guarantee of eliminating all negative incrementals. It is the most conservative option since stream flows are reduced rather than increased or left unaltered. If option 2 is used in combination with the channel loss option, the loss factors $CL(cp)$ are reflected in the computation of downstream negative incremental flow adjustments. The channel loss option is treated as an integral part of option 2, and these two modeling features may be used in combination.

Option 3 consists of adjusting the naturalized stream flows at all control points by adding the downstream flow adjustments. All negative incrementals are alleviated. The adjusted total flows are determined prior to the simulation and simply replace the original naturalized flows. The flows can be adjusted by either *SIM* or *HYD*. This approach makes the maximum amount of water available to the water rights. The problem is that water is arbitrarily added to the system, likely resulting in inappropriately high indications of water supply availability/reliability. Option 3 includes no features for integrating it with the channel loss option. Option 3 and the channel loss option should not be used in combination because adjustments to remove the effects of channel losses will be reflected twice.

Options -3 and -4 are variations of options 3 and 4 in which incremental flows are defined in terms of only those control points for which *INMETHOD* in *CP* record field 6 is 0, 1, or 2. This includes the control points for which inflows *IN* records are entered in the *SIM* input data and those for which flows are transferred using *INMETHOD* option 2. Control points for which flow distribution methods 3, 4, 5, 6, 7, and 8 are applied to determine naturalized flows are excluded in defining incremental flows or applying negative incremental flow adjustments.

Option 4 involves the same flow adjustments as option 3. However, in considering each water right in turn, the flow adjustment is made available at downstream control points but not at the control point of the right. For example, referring to column 7 of Table 3.3, the available flow of 81 ac-ft at CP-2 is determined as the minimum of the following values.

$$\begin{aligned} \text{CP-2: } & 81 \\ \text{CP-4: } & 104 = 100 + 4 \\ \text{CP-6: } & 112 = 80 + 32 \end{aligned}$$

Adjustments are added to the flows at the downstream CP-4 and CP-6 but not at the location (CP-2) of the water right. Thus, negative incrementals occurring downstream do not affect the amount of water available to a right. However, negative incrementals in the reaches upstream of the water right do affect its water availability. Option 4 is the most realistic assumption in many actual river basin modeling situations. Option 4 includes the following other special features which are not included in option 3.

- With option 4, if pertinent channel loss factors $CL(cp)$ are non-zero, the amount of water available to a water right is determined as the greater of the amount considering either the channel loss factors or negative flow adjustment but not both.
- With option 4, the negative incremental flow adjustments are not applied to regulated flows.

The negative incremental flow adjustments affect the amount of stream flow available to a water right and affect unappropriated flows but do not affect regulated stream flows. Regulated flows logically should not be adjusted for negative incremental inflows occurring downstream.

Channel loss computations activated by non-zero loss factors on CP records are used in combination with negative incremental adjustment option 4. However, the negative incremental flow adjustment is a correction for channel losses as well as other factors. Therefore, in the water rights computational loop, in determining water availability for a particular right in a particular month, the channel losses factors $CL(cp)$ and negative incremental flow adjustments are not both applied concurrently. Rather, each is applied individually, and the method providing the greatest water availability is adopted. As previously discussed, the model checks available stream flow at all downstream control points as well as at the control point at which the right is located. At each downstream control point, water availability is determined alternatively (1) using the $CL(cp)$ to cascade back upstream and (2) applying the incremental flow adjustment. The method yielding the highest water availability is selected. Channel losses are identically the same with ADJINC of either -4 or 4. Channel losses are computed for all control points with non-zero $CL(cp)$ either way.

In Example 3 presented in Figure 3.2 and Tables 3.2 and 3.3, if $CL(cp)$ for control points CP-1 and CP-4 are 0.1 and 0.2, respectively, the available flow of 90 ac-ft at CP-2 is determined as the minimum of the following values.

$$\begin{aligned} \text{CP-1: } & 90 \\ \text{CP-2: } & 90 = \text{maximum of: } \begin{aligned} & 81 / [1.0(1.0 - CL(I))] = 81 / 0.9 = 90 \\ & 81 + 9 = 90 \end{aligned} \\ \text{CP-4: } & 111 = \text{maximum of: } \begin{aligned} & 100 / [1.0(1.0 - CL(I))] = 100 / 0.9 = 111 \\ & 100 + 4 = 104 \end{aligned} \\ \text{CP-6: } & 112 = \text{maximum of: } \begin{aligned} & 80 / [(1.0 - CL(4))(1.0)(1.0 - CL(I))] = 80 / [(0.8)(0.9)] = 111 \\ & 80 + 32 = 112 \end{aligned} \end{aligned}$$

The available flow of 81 ac-ft at CP-2 is determined as the minimum of the following values.

CP-2: 81

CP-4: 111 = maximum of: $100 / [1.0(1.0 - CL(I))] = 100 / 0.9 = 111$
 $100 + 4 = 104$

CP-6: 112 = maximum of: $80 / [(1.0 - CL(4))(1.0)(1.0 - CL(I))] = 80 / [(0.8)(0.9)] = 111$
 $80 + 32 = 112$

The available flow of 100 ac-ft at CP-4 is determined as the minimum of the following values.

CP-4: 100

CP-6: 112 = maximum of: $80 / (1.0 - 0.2) = 100$
 $80 + 32 = 112$

Simulation steps. Regardless of negative incremental option, in each month, as each water right is considered in turn in priority order, the *SIM* simulation proceeds through three steps:

1. The amount of stream flow available to that water right is determined as the minimum of available stream flows at the control point of the right and downstream control points.
2. Water accounting computations are performed to determine the stream flow depletion, return flow, reservoir storage contents, and other quantities for the water right.
3. Stream flows at downstream control points are adjusted for the effects of the water right.

Option 5 is a modified version of the algorithms for the first and third steps listed above. With option 5, incremental flows are not computed, and there is no negative flow adjustment array developed prior to the simulation like options 2, 3, and 4. Option 5 is incorporated in steps 1 and 3 listed above as follows.

- In the above step 1 determination of the amount of stream flow available to a water right, with option 5, the only downstream control points considered are those at which senior rights are located. Furthermore, no control points with zero flow or located downstream of a discontinuity of flow (control point with zero flow) are considered regardless of senior rights.
- In the third step listed above, option 5 limits the flow adjustment to not exceed the minimum of the regulated flows at any of the intermediate control points between the current upstream water right being simulated and downstream senior rights. The adjustments stop if a control point with zero regulated flow is encountered. Option 5 is the only *ADJINC* option that includes modification of the step 3 computations.

Option 6 is a modified version of option 4 designed to reduce computer execution time. Regardless of *ADJINC* option, the amount of stream flow available to a water right is determined as the minimum of available flows at the control point of the right and relevant downstream control points. Option 4 considers all downstream control points in searching for the constraining site without identifying which of the downstream control points represent locations of water rights that are senior to the current water right being simulated. Option 6 identifies the control points at which relevant senior rights are located and limits consideration to only those control points. Relevant

downstream senior rights are those that appropriate stream flow which excludes types 3, 4, and 6 specified by *WR* record field 6 and defined in Chapter 4. Option 6 also stops the cascading search for the minimum flow whenever a control point with zero flow is found.

Option 6 allows *SIM* to run a little faster than option 4. With negative incremental flow adjustments applied, senior rights are the only downstream constraint on the flow available to upstream water rights. Thus, options 6 and 4 always yield the same simulation results.

Option 7 is designed to be the standard *ADJINC* option to be adopted in *SIMD* whenever routing and forecasting are employed, but can also be used in a monthly or daily simulation without routing and forecasting. As explained in the *Daily Manual*, in applying option 7 with *SIMD* routing and forecasting, the downstream control points identified in the *SIMD* reverse routing are further constrained to only those control points at which relevant senior rights are located. Relevant downstream senior rights are those that appropriate stream flow which include instream flow *IF* record rights and *WR* record types 1, 2, 5, and 7 as defined in Chapter 4.

Flows at downstream control points with no senior rights have no effect on water availability for the junior right with option 7. Therefore, negative incremental flows at a downstream control point affect the amount of flow available to a particular water right only if senior rights also reduce the flows at the downstream control point. Option 7 is similar to option 5 but does not include all of the features of option 5. Option 7 is option 1 with the limitation to senior right control points added. Relevant senior rights are the same with options 6 and 7.

Option 8 ignores downstream control points in the determination of the amount of stream flow available to a water right. Thus, junior water rights can erroneously appropriate stream flow that has already been appropriated by downstream senior rights. This *double-taking* of the same water introduces errors in the simulation. Option 8 is valid only if all water right priorities correspond to upstream-to-downstream order. Thus, option 8 should normally not be adopted except for experimentation. Option 8 is designed for experimentation. The effects on junior rights resulting from not passing inflows to protect downstream senior rights can be explored.

Examples Comparing Options 1, 4, 5, 6, and 7

The following simple examples are used to compare *ADJINC* options 1, 4&6, 5, and 7. Options 4 and 6 are the same. Referring to Example A, with either option 1, 4, 5, 6, or 7:

- With $CL = 0.5$ for CP2, a senior stream flow depletion of 80 at CP1 would reduce the flow at CP3 from 40 to zero. A CP1 depletion of 50 would reduce the CP3 flow to 15.
- The maximum amount of water available at CP3 is 40.
- A senior right of up to 40 at CP3 will be met without shortage.

In Example A, with option 1, water availability at CP1 is limited by the flow at CP3 regardless of whether there is a senior right at CP3. With options 4 and 6, water availability at CP1 is not limited by negative incremental flow occurring downstream. With options 5 and 7, water availability at CP1 is limited by the flow at CP3 only if there is a senior right at CP3.

Example A. CP3 is downstream of CP2 and CP1. Naturalized flows at CP1, CP2, and CP3 are 100, 110, and 40. Thus, the option 4 incremental flow adjustment at CP3 is 70. The CP2 channel loss factor CL is 0.50 for reach CP2-CP3. The amount available for a senior right at CP3 is 40 for all three options. The effect of a water right diversion of 30 at CP3 on the amount of water available for a water right at CP1 is shown as follows for negative incremental inflow options 1, 4, and 5.

$$\text{CP1 (100)} \rightarrow \text{CP2 (110)} \rightarrow \text{CP3 (40)}$$

Amount of Water Available to a Water Right WR1 at Upstream CP1

Negative Incremental Flow Option	Option 1	Options 4,6	Options 5,7
WR1 at CP1 is senior to diversion of 30 at CP3	80	100	100
WR1 at CP1 is junior to diversion of 30 at CP3	20	80	20

computed as follows

Option 1	Options 4 and 6	Options 5 or 7
40/0.5=80	Min[100 and maximum of (40+70=110 and 40/0.5=80)] = 100	100 at CP1
10/0.5=20	Min[100 and maximum of (10+70=80 and 10/0.5=20)] = 80	10/0.5=20

Example B. Example B is identical to Example A, except the naturalized flow at CP3 is zero. The amount available for a water right at CP3 is zero for all three options.

$$\text{CP1 (100)} \rightarrow \text{CP2 (110)} \rightarrow \text{CP3 (0)}$$

Amount of Water Available to a Water Right WR1 at Upstream CP1

Negative Incremental Flow Option	1	4,6	5	7
WR1 at CP1 is senior to WR of any amount at CP3	0	100	100	100
WR1 at CP1 is junior to WR of any amount at CP3	0	100	100	0

computed as follows

Option 1	Options 4 and 6	Options 5 or 7
0/0.5=0	Min[100 and maximum of (0+110=110 and 0/0.5=0)] = 100	100 at CP1
0/0.5=0	Min[100 and maximum of (0+110=110 and 0/0.5=0)] = 100	100 at CP1

Example C. CP1, CP2, CP3, CP4, and CP5 are in series, with flows of 100, 110, 120, 10, and 130. Between CP3 and CP4, the incremental flow is -110, and the channel loss factor CL is 0.50. The effect of a water right diversion of 10 at CP4 on the amount of water available for a water right WR1 at CP1 is tabulated below.

CP1: 100
 ↓
 CP2: 110
 ↓
 CP3: 120
 ↓
 CP4: 10
 ↓
 CP5: 130

Amount of Water Available to a Water Right WR1 at Upstream CP1

Negative Incremental Flow Option	Option 1	Options 4,6	Options 5,7
WR1 at CP1 is senior to diversion of 10 at CP4	20	100	100
WR1 at CP1 is junior to diversion of 10 at CP4	0	100	0

computed as follows

Option 1	Options 4 and 6	Options 5 or 7
10/0.5=20	Min[100 and maximum of (0+110=110 and 10/0.5=20)] = 100	100 at CP1
0/0.5=0	Min[100 and maximum of (0+110=110 and 0/0.5=0)] = 100	0/0.5 at CP4

Example D. Example D is identical to Example C except the diversion of 10 is moved to CP5.

Amount of Water Available to a Right WR1 at Upstream CP1

Negative Incremental Flow Option	Option 1	Options 4,6	Options 5,7
WR1 at CP1 is senior to diversion of 10 at CP4	20	100	100
WR1 at CP1 is junior to diversion of 10 at CP4	20	100	100

computed as follows

Option 1	Options 4 and 6	Options 5 or 7
10/0.5=20	Min[100 and maximum of (0+110=110 and 10/0.5=20)] = 100	100 at CP1
10/0.5=20	Min[100 and maximum of (0+110=110 and 10/0.5=20)] = 100	100 at CP1

With option 1, stream flow availability may be limited by negative incremental flows at any downstream control point with or without senior rights. With options 4 and 6, flow availability is never limited by negative incremental flows at downstream control points regardless of senior rights. With options 5 and 7, stream flow availability may or may not be limited by flows at downstream control points depending on senior rights.

Considerations in Comparing ADJINC Options

The combination of actual factors causing negative incrementals may vary between months and between control points. The basic reasons for negative incrementals are as follows.

1. permanent channel losses over and above those modeled by the channel loss coefficients included in the *SIM* input dataset and associated computational routines
2. temporary channel losses, again over and above those captured by the *SIM* channel loss computations, where bank storage or underflow may reenter the stream at a downstream location and/or during a future time period
3. timing effects of runoff from a rainfall event reaching an upstream control point in a particular month but reaching a downstream control point early in the next month
4. inaccuracies and lack of precision in stream flow measurements at gages and in computations to convert gaged flows to naturalized flows
5. peculiarities in *SIM* input datasets in establishing control points and assigning naturalized flows to the control points

The uncertainties associated with combinations of the factors listed above are inherent in the model even if all incremental flows are positive. Negative incremental flows simply result in the effects being more obvious. Simulation results should be identical for all of the *ADJINC* options (except option 8) if there are no negative incremental flows.

Senior rights are protected from junior rights regardless of which *ADJINC* option is selected to deal with negative incremental flows. In all cases, stream flows are allowed to "*pass through*" to accommodate senior water rights located downstream. The *ADJINC* options differ in regard to whether junior right appropriations are also curtailed to "*pass through*" flows to mitigate negative incremental flows occurring downstream even though the flows available to senior rights are not increased in the model by this curtailment. In comparing *ADJINC* options, the following key question is considered from the perspective of properly modeling the impacts of senior rights on junior rights, not vice versa. In order to not reduce flows physically available for senior water right requirements at downstream locations, must upstream water rights allow sufficient stream flows to pass their locations to cover the negative incremental flows occurring in river reaches in between, in addition to maintaining flows available to the senior rights?

Summary Comparison of ADJINC Options

Option 4 has been the standard *ADJINC* option recommended in the *Reference Manual* for most applications since the initial versions of WRAP. Option 6 was added in 2011 for the sole purpose of reducing computer execution time while replicating option 4 simulation results. Options 6 and 4 yield the same simulation results though option 6 runs a little faster. Option 6 is now the default standard option for a monthly simulation or sub-monthly (daily) simulation without routing. Option 7 is the recommended standard for a sub-monthly (daily) simulation with routing and forecasting. The 2011 addition of option 7 was motivated by the daily *SIMD* but is also applicable for monthly *SIM* simulations. Option 5 provides an alternative viable methodology which has also been routinely applied with the TCEQ WAM System datasets.

With options 4 and 6, stream flow availability for a water right is not affected by negative incremental flows occurring downstream. With options 1, 2, 5, and 7, the amount of water available to a right may be reduced by negative incremental flows occurring at downstream control points. With options 5 and 7, the amount of water available to a right is reduced by negative incremental flows occurring only at those downstream control points at which are located water rights that are senior to the water right currently being simulated.

The following premises are reflected in the alternative *ADJINC* options in determining the amount of stream available to each water right. The term *excess negative incremental flow* is adopted here to refer to the portion of a negative incremental flow not accounted for by the *SIM* channel loss computations that use the channel loss factors provided as input on *CP* records.

- Option 1 is based on the premise that flow at upstream locations must be committed to mitigating excess negative incremental flows at all downstream control points to prevent negative regulated flows either with or without the existence of downstream senior rights.
- Option 5 is based on the premise that upstream flows must mitigate downstream excess negative incremental flows prior to meeting water right requirements unless: (1) there is no downstream senior water right that affects upstream water availability or (2) there is a discontinuity of flow (zero flow) between the control point of the downstream senior right and the upstream control point for which water availability is being determined. The premise is that junior rights located upstream must curtail stream flow depletions as necessary to mitigate excess negative incremental flows (viewed primarily as channel losses) even though the curtailment does not increase the flow available to downstream senior rights.
- Option 7 is likewise based on the premise that upstream flow must be used to mitigate excess negative incremental flows prior to meeting downstream water right requirements. Incremental flows are considered only at downstream control points at which relevant senior rights are located. Senior rights are relevant only if they are *WR* record field 6 type 1, 2, 5, or 7 rights (defined in Chapter 4) which appropriate stream flow or instream flow *IF* record rights. In a *SIMD* daily simulation, only control points identified in the reverse routing algorithm described by the *Daily Manual* are considered.
- Options 4 and 6 are based on the premise that excess negative incremental flows at downstream control points do not affect water availability for water rights located at an upstream control point. Stream flows are passed to meet senior water right requirements at downstream control points, adjusted for channel losses computed based on the channel loss factors entered on the *CP* records. However, water availability at an upstream control point is not reduced for negative incremental flows assigned to downstream control points.

Another difference between option 5 and the other *ADJINC* options relates to flow adjustments for the effects of stream flow depletions. In cascading downstream flow reductions resulting from stream flow depletions made by water rights, option 5 limits the flow adjustment to not exceed the minimum regulated flow at intermediate control points. The other *ADJINC* options include no modifications to the algorithms that cascade the effects of water rights on downstream flows. With options other than option 5, the flow at a downstream control point can be reduced more than the regulated flow of another intermediate control point located upstream.

CHAPTER 4

WATER MANAGEMENT IN THE SIMULATION MODEL

A *WRAP-SIM* simulation combines

sequences of naturalized stream flows and reservoir net evaporation-precipitation rates representing river basin hydrology, as discussed in the preceding Chapter 3, with water rights information representing the manner in which water resources are developed, regulated, allocated, and used, as discussed in the present Chapter 4.

WRAP is motivated by the Texas prior appropriation water right permit system but provides flexible capabilities for modeling water management situations anywhere that may or may not involve actual water rights. A broad spectrum of water allocation schemes may be simulated. Constructed facilities, water use requirements, and river/reservoir system operating practices are referred to generically as *water rights* in WRAP. This chapter describes capabilities provided by *WRAP-SIM* for modeling a water resources development/management/use system consisting of:

- reservoir projects operated to regulate and conserve river flow, off-channel storage reservoirs, pumping/conveyance facilities, and hydroelectric power plants
- international treaties, interstate compacts, interagency contracts, and other agreements
- requirements specified in water right permits
- river/reservoir system operating policies and rules
- water use requirements, characteristics, and practices

Water Rights

In WRAP terminology, a water right is a set of water management capabilities and use requirements associated with either a water right *WR* record or an instream flow *IF* record. *UC, UP, DI, IS, IP, RF, WS, OR, HP, SO, ML, TO, LO, FS, CV, TS, and PX* records are connected to a *WR* or *IF* record to provide additional information regarding water management and use specifications. Refilling reservoir storage, water supply diversions, and hydroelectric energy generation are specified as *WR* record rights. Environmental instream flow requirements are specified as *IF* record rights. *SIMD* flood control operations covered in the *Daily Manual* are defined as *FR/FF* record rights. The number of rights counted by *SIM* is simply the number of *WR* and *IF* records in the input file. In modeling a permit system, the total number of rights (*WR* and *IF* records) counted by the model typically does not necessarily correspond to the number of actual water right permits.

A key aspect of applying WRAP is ingenuity in combining water right *WR*, instream flow *IF*, and supporting input records to model a particular water management situation. The model provides considerable flexibility in defining water management/use requirements and capabilities. An actual water right permit may be represented by any number of *model water rights*. A single appropriator holding a single water right permit may have several model rights representing different features of the water right permit. For example, a water right that includes three different uses, such as municipal, industrial, and irrigation, would be treated as three separate *WR* record rights, since the monthly water use distribution factors are different for the various uses. A water supply diversion and storage capacity can be assigned different priorities by treating them as two

separate rights, a diversion right with no storage capacity and a storage right with a zero diversion. A reservoir may have several rights with different combinations of priority dates and storage capacities. Any number of rights may be associated with the same reservoir. Likewise, multiple reservoirs may be associated with a single right. Also, in certain applications, several actual permitted water rights may be combined and inputted to the model as a single aggregate water right.

The set of information specifying the water management and use requirements defining a particular water right may include the following.

- identifiers of the control point locations of pertinent components
- priority number or information that assigns a priority number
- annual diversion target
- return flow specifications
- instream flow specifications
- annual hydroelectric energy generation target
- set of monthly water use distribution coefficients
- set of rules for varying diversion, instream flow, and hydroelectric energy targets as a function of stream flow subject to specified limits
- drought index for varying targets as a function of reservoir storage
- active and inactive reservoir storage capacity
- reservoir storage volume versus surface area relationship
- reservoir water surface elevation versus storage volume relationship
- reservoir/river system operating rules
- off-channel reservoir storage
- interbasin or intrabasin conveyance
- specified limits or rules for computing limits on stream flow depletions
- annual limits on total diversions or diversions from storage
- identifiers for labeling rights and aggregating simulation results for groups of related rights

Most of the records and record fields for entering water rights information are optional. The control point location and priority number are actually the only required information for a water right. The priority number field may be left blank but will then default to zero. Each control point identifier on *WR* or *IF* records must match an identifier on a *CP* record. Control point identifiers are required to define the spatial connectivity of a river basin system. Water right identifiers are also entered on *WR* and *IF* records for use in labeling input and output data and aggregating simulation results for groups of related rights. However, water right identifiers are not actually required in the simulation computations.

Water supply diversion, hydroelectric energy generation, and instream flow requirements are specified in terms of an annual amount input on a *WR* or *IF* record combined with a set of 12 monthly use coefficients specified on *UC* records for distributing the annual amount over the 12 months of the year. Thus, water use requirements may be expressed as monthly targets that may vary each month from January through December but are constant from year to year. Options also allow targets to be defined as a function of reservoir storage and/or stream flow. *HC*, *ES*, *PF*, and records express instream flow *IF* record rights in environmental flow standard format.

Water Right Priorities

The allocation of water among water rights in *WRAP-SIM* is based on priority numbers. The integer priority numbers serve the important function of setting the order in which the rights are considered in the water rights computational loop that allocates water, but are used in no other way. Diversion, instream flow, hydropower, and storage refilling targets for each right are met to the extent allowed by available stream flow and storage prior to considering the requirements of more junior rights. A fundamental concept of the model is that available stream flow is allocated to each water right in turn in ranked priority order. The seniority of a right relative to other rights is expressed by their priority numbers. A smaller priority number means higher priority, rank, or seniority. In comparing two rights, the senior right has a lower priority number than the junior right. *Junior* and *senior* are relative terms used in the context of comparing the priority of two rights.

Within the *SIM* computations, the magnitude of the priority numbers for each of the rights relative to each other govern the sequencing of computations and thus water allocation among the rights. In the Texas prior appropriation water rights permit system, priority numbers typically represent dates specified in the permits. For example, a priority date of June 25, 1978 specified in a water right permit is entered in field 5 of the *WR* record as the integer 19780625, which is a larger number than the priority corresponding to any earlier date. However, with a little ingenuity, the model-user can devise various other schemes for using the priority numbers to model relative priorities for allocating water. *SIM* also has alternative options other than the priorities on *WR* and *IF* input records for assigning priorities and also has options for circumventing the priority system.

Priorities are integer numbers specified for each water right. Smaller integers mean rights are considered earlier in the priority-based computational sequence (Figure 2.2). With the standard default system for assigning priorities, the model-user assigns each water right its own unique priority by entries in *WR* and *IF* record field 5. This standard default and other optional alternative methods for ranking all water rights (*WR* and *IF* records) in priority order are described as follows.

1. A priority number for each water right is entered in field 5 of its *WR* or *IF* records. A blank field 5 is read as a priority number of zero. If two or more rights have the same priority number, they are ranked in the same order as their *WR* or *IF* records are entered in the input file.
2. Factors entered on a use priority *UP* record replace or modify the *WR/IF* field 5 priority numbers for all *WR* and *IF* records having the same water use type identifier as the *UP* record.
3. *JO* record field 13 parameter *NPOPT* activates optional methods for assigning priorities that replace the priorities assigned in *WR* and *IF* record field 5. These options set priorities either automatically in upstream-to-downstream order (*NPOPT* option 1) or based on the order in which *WR/IF* records (option 2) or *CP* records (option 3) are placed in the DAT input file.
4. Options provided on *PX/AV* and *EA/EF/AF* records allow two or more rights to share the same priority. Stream flow and storage are allocated between these rights in accordance with rules governed by parameters provided as input by the model-user.

Water use types serve the primary purpose of specifying coefficients for distributing annual use targets over the 12 months of the year but also can be used in specifying priorities for groups of rights. Examples of possible water use types include municipal, various types of industrial, various

types of agricultural, mining, or any other categories of interest. Field 4 of the *WR* and *IF* records provides a water use identifier that connects the right with water use distribution coefficient (*UC*) and use priority (*UP*) records. The following factors may be entered on a *UP* record.

- integer priority number that overrides the *WR/IF* record priority number
- integer number to be added to the *WR/IF* record priority numbers
- factor by which the target diversion, instream flow, or hydropower target amounts from the *WR/IF* records are to be multiplied

These factors are applied to all rights that have the pertinent use type identifier on the *WR* or *IF* record. For example, the effects of making municipal rights senior to all other rights may be conveniently simulated by subtracting some integer from the priorities for all municipal rights that makes them smaller and thus senior to all other rights. Likewise, an alternative simulation examining the effects of a 20 percent reduction in municipal water use targets could be easily made.

The following options replace the priorities entered in *WR* and *IF* record field 5. The *WR/IF* field 5 priority number is ignored. The switch parameter *NPOPT* in *JO* record field 13 activates three alternative options for setting priorities.

JO record *NPOPT* option 1, called the natural priority option, provides the capability to conveniently simulate water management in a river basin that has no water allocation priority system. Without a water rights permit system or some other regulatory mechanism to allocate water, water availability for each water user is affected by other water users located upstream but not by those downstream. Priorities may be manually assigned to each water right to simulate this upstream-to-downstream natural priority system. However, *JO* record *NPOPT* option 1 allows the upstream-to-downstream priorities to be activated automatically. *SIM* internally assigns priority numbers to water rights based on the location of their control points. The control points are automatically assigned integer priority numbers starting with 100 and increasing in increments of 100 following the criterion that the integer assigned to any control point is smaller than the number assigned to any other control point located downstream. For control points on parallel tributaries, those listed in the input file first are considered first in the algorithm and get the smaller priority number. Each water right is then assigned the number associated with its control point. For multiple rights at the same control point, the priority number is incremented based relative priorities on their *WR* and/or *IF* records. For example, four water rights at a control point with priority number 800 will be assigned priority numbers 800, 801, 802, 803 based upon the relative priorities on their *WR* or *IF* records.

With *JO* record *NPOPT* option 2, priorities are based simply on the order in which *WR* and *IF* records are placed in the DAT input files. The first right read by *SIM* from the input file is most senior with the priority number 1. The second and third *WR* or *IF* records have priorities 2 and 3.

With *JO* record *NPOPT* option 3, priorities are based on the order that control point *CP* records are placed in the input file. For multiple water rights located at the same control point, relative priority rankings are based on the order of the *WR* and *IF* records in the input file.

PX/AV and *EA/EF/AF* record options described later in this chapter allocate water between rights sharing the same priority. Capabilities are provided for circumventing the priority system.

Water Availability within the Priority-Based Water Rights Computation Loop

The *WRAP-SIM* simulation approach is built on the fundamental concept of water allocation computations being performed in a water rights loop in which the requirements of each individual right are met in priority order. Thus, senior rights affect the amount of water available to junior rights but are not adversely affected by the junior rights. However, the simulation is complicated by situations in which junior rights may increase the amount of water available to senior rights. Fluctuating decreases and increases in water availability are a complexity in applying *SIM* that must be considered in applying the methods outlined in this chapter. Modeling difficulties may occur involving senior rights not getting access to water made available by junior rights through:

1. same-month return flows from diversions from storage
2. same-month hydroelectric power releases
3. contributions to meeting instream flow requirements at intermediate control points made by releases from upstream reservoirs to meet diversions at downstream locations

As each water right is considered in priority order in the water rights computational loop, regulated flows and the flows available to more-junior rights usually decrease but may also increase. Diversions and filling reservoir storage decrease flows at their control point and at downstream control points. Conversely, flows are increased by hydropower releases and return flows from diversions from storage. Reservoir releases may increase flows at intermediate control points between the reservoir and downstream diversion site. A diversion and/or storage right may be unnecessarily curtailed (shorted) due to computationally not having access to water made available by more junior rights in the form of return flows or hydropower releases. Likewise, reservoir releases that increase flows at intermediate control points between the reservoir and downstream diversion site may not be properly credited as contributing to instream flows at the intermediate control points. Junior diversion and storage rights may be unnecessarily curtailed to maintain senior instream flow requirements.

The following *SIM* options have been adopted in practice to deal with the complexities of fluctuating decreases and increases in water availability in the water rights priority loop. These options involve model features described throughout the remainder of this chapter. The next-month return flow option makes the return flows available in the next month at the beginning of the water rights loop. Likewise, modeling return flows as constant inflows on *CI* records makes the flows available at the beginning of the water right computations. Thus, all rights have access to the return flows in priority order. The next-month hydropower option serves this same purpose for power releases. The optional second-pass feature associated with *IF* record rights addresses this same complexity from the perspective of instream flow requirements. Since return flows and hydropower releases are usually handled with next-month options and *CI* record inflows, the second pass instream flow option is probably most relevant for situations in which reservoir releases increase flows at intermediate control points between the reservoir and downstream diversion site. The transient priority XP option 1 on the *PX* record allows the return flow to be assigned a priority that is different than the diversion priority. Other *PX* record options are designed to circumvent the priority sequence for other purposes.

Water Right Types

All *WR* record water rights are categorized as being either type 1, 2, 3, 4, 5, 6, 7, or 8 by the entry in field 6 of the *WR* record. This categorization by type is not applicable to instream flow *IF* record water rights. This scheme of water right types is used to specify certain basic rules for meeting diversion or hydroelectric energy requirements from stream flow and reservoir storage and for refilling reservoir storage. The kinds of river/reservoir system operations associated with each type of water right are described as follows.

- Type 1:* default standard right may include diversion and return flow, refilling storage in one reservoir, and releases from any number of reservoirs. Diversion requirements are met from reservoir storage if and only if sufficient stream flow is not available.
- Type 2:* same as type 1 except that refilling of reservoir storage is not allowed
- Type 3:* same as type 2 except diversions can be supplied only from reservoir storage
- Type 4:* flow is discharged into the stream
- Type 5:* hydropower right, same as type 1 except a hydroelectric energy generation requirement is specified instead of a diversion requirement
- Type 6:* hydropower right with stream flow depletions not allowed, meaning electric energy is generated only from releases from reservoir storage and the reservoir is not refilled
- Type 7:* reservoir storage refilling target is determined and applied
- Type 8:* target is computed solely for use by other water rights that reference the target

Table 4.1
Features of Each Water Right Type

River/Reservoir System Operation	Water Right Type (<i>WR</i> Record Field 6)							
	1	2	3	4	5	6	7	8
water supply diversion from stream flow	yes	yes	–	–	–	–	–	–
hydroelectric power generation	–	–	–	–	yes	yes	–	–
releases from one or multiple reservoirs	yes	yes	Yes	–	yes	yes	–	–
refill storage in one reservoir	yes	–	–	–	yes	–	yes	–
discharge of inflows into the river	–	–	–	yes	–	–	–	–

Type 1, 2, 3, 5, and 6 rights allow releases from reservoirs to meet either diversion (types 1, 2, 3) or hydropower (types 5, 6) requirements specified on *WR* and associated records. However, reservoir storage may be refilled only by type 1, 5, and 7 rights. Thus, at least one type 1, 5, or 7 right must be connected to every reservoir. A type 1 right is often used to refill a reservoir from which draw-downs are made by type 2, 3, and/or 6 rights and perhaps other type 1 or type 5 rights. Refilling storage may be assigned a different priority than withdrawals and releases from storage.

If one or more *WS* records are connected to an *IF* record, reservoir operation is equivalent to *WR* record type 2. Releases are made from the reservoirs to meet the instream flow requirement.

However, an *IF* record does not refill storage. In general, all junior rights must pass inflows through their reservoirs to meet downstream instream flow requirements. Using one or more *WS* records to assign reservoir storage to an *IF* record right is relevant only if releases from storage are required, in addition to passing reservoir inflows, to meet instream flow requirements.

Type 1 right.- Most water rights in a typical river basin will likely be represented as type 1 rights. A type 1 right allows a diversion to be met from stream flow depletions and/or storage in one or more reservoirs. A diversion requirement is met first from stream flow, if available, and then from reservoir storage if stream flow is not available. One reservoir, called the primary reservoir, can be refilled from stream flow depletions or releases from other reservoirs in the system. The one primary reservoir that can be refilled and the diversion, if any, associated with that *WR* record must be located at the same control point. The other reservoirs in the system, from which releases or withdrawals are made, can be located at any of the control points. A storage-only right may simply refill storage in the one reservoir, having a diversion requirement of zero. A run-of-river diversion right can be represented as a type 1 or type 2 right with zero active reservoir storage capacity.

Type 2 right.- A type 2 right is identical to a type 1 right except that reservoir storage is not refilled. Reservoirs may be used along with stream flow to meet diversion requirements, but other rights are used to refill storage. Another type 1 right refills the reservoir storage. A type 1 right allows both a diversion and refilling of storage, but the diversion and reservoir must be at the same location. If a diversion is at a location different than the location of the reservoir, a type 2 or 3 right with an operating rules *OR* record is required.

Type 3 right.- A type 3 right is identical to a type 2 right except the diversion target can be met only by releases or withdrawals from reservoir storage. For example, a diversion could be met by releases from one or more upstream reservoirs without allowing diversion of unregulated stream flow entering the river below the dams. Unlike a type 3 right, a type 1 or 2 right makes reservoir releases only after the stream flow at the diversion location is depleted.

Type 4 right.- With a type 4 right, the annual amount *AMT* entered in *WR* record field 3 is discharged into the stream. The stream inflow amounts resulting from type 4 rights are found in the simulation results as return flows. A type 4 right may model an interbasin transfer of water through conveyance facilities, return flow from groundwater sources, or other situations involving discharge of water into the river system within the water rights priority computation loop sequence. The target amount is computed for a type 4 right just like any other type of right. The difference is that a type 4 right is not a diversion from the stream, but rather an inflow to the stream. After the monthly amount is determined just like a diversion target, it is then multiplied by the return flow factor *RFAC* from *WR* field 8 and treated computationally as a return flow. *RFAC* is assigned a default of 1.0 if the *RFAC* field is blank. All return flow options are valid, except monthly return factors (*RF* records) cannot be used. Water availability computations are not relevant and are not performed for a type 4 right. The flow is entered into the stream system; it is not taken from stream flow, reservoir storage, or any other source included in the model.

Type 5 right.- A hydropower right is identical to a type 1 right except a hydroelectric energy requirement is specified rather than a diversion. A 5 or -1 is entered in *WR* record field 6 for a hydropower right. A run-of-river hydropower right can be represented as a type 5 right with one reservoir with inactive but no active storage capacity. Hydropower rights are not affected by *IF*

record rights. Use of separate *WR* record type 1 rights to refill reservoir storage at a hydropower reservoir project may be required to protect *IF* record instream flow requirements.

Type 6 right.- A type 6 hydropower right is analogous to a type 3 diversion right. A 6 or -3 is entered in *WR* record field 6. The only difference between types 5 and 6 is that type 6 does not allow access to stream flow. Stream flow depletions are zero and thus storage cannot be refilled.

Type 7 right.- A type 7 right refills storage in a reservoir based on a storage target computed in identically the same manner as a diversion target. Options for setting diversion targets using *WR*, *UC*, *DI/IS/IP*, *TO*, *TS*, *FS*, and *SO* record options are applied in exactly the same way to set a type 7 right storage target starting with *AMT* in *WR* record field 3 which is distributed over the 12 months of the year. However, the target is a storage capacity to which the reservoir is filled subject to water availability and the constraint of not exceeding the capacity entered in *WS* record field 3. Thus, as long as the target does not exceed the normal *WS* record field 3 capacity, the target is treated as the storage capacity. There is no diversion or hydropower generation associated with a type 7 water right. A type 7 right does nothing but refill reservoir storage.

Type 8 right.- A type 8 right only creates a target volume and/or flow switch with no other computations performed for that water right. Targets can be developed using *UC*, *TO*, *TS*, *SO*, *DI/IS/IP*, *BU*, *CV*, and *FS* records along with the *WR* record target setting features. However, the target for a type 8 water right is not used by that right, and the right is not further simulated. The only reason for a type 8 water right is to allow its target to be used by one or more other *WR* or *IF* record water rights in assigning or adjusting their instream flow, diversion, hydropower, or storage targets, reservoir release limits, or stream flow depletion limits. A type 8 right, like any other right, can be referenced by *HC*, *TO*, *LO*, *FS*, and *CV* records. *WR*, *IF*, and *OR* records can connect to *FS* or *CV* records contained with the record set of another water right.

Primary and Secondary Reservoirs

A water right can be associated with any number of reservoirs. A *WS* record for each reservoir must follow the *WR* record. Only one reservoir, called the primary reservoir, is allowed to refill storage with that particular right. The water right diversion and primary reservoir must be located at the same control point. Types 1, 5, and 7 rights are the only water rights allowed to refill storage. A type 1 right or hydropower right may have either zero or one primary reservoir and any number of secondary reservoirs. A type 7 right must have one primary reservoir and may have any number of secondary reservoirs. The primary reservoir must be cited on the *WS* record immediately following the *WR* record. All reservoirs on the second and subsequent *WS* records are termed secondary reservoirs and can only make releases for the water right, not be refilled by it. All reservoirs associated with type 2, 3, or 6 rights are classified as secondary reservoirs. These reservoirs are refilled by other rights. Likewise, *IF* record rights do not refill reservoir storage.

Water Right Types 1, 2, 3, and 7 in the WRAP-SIM Simulation

The water right type specified on the *WR* record guides the computations within the *WRAP-SIM* water rights loop. The type specification primarily affects the determination of the target requirement for the right and the manner in which the requirement is to be met. The available stream flow is calculated the same regardless of water right type, except hydropower rights are not

subject to instream flow requirements. The target stream flow depletion is then computed according to the type of right.

For type 1 rights, the target stream flow depletion is the permitted diversion amount plus the volume needed to refill storage in the primary reservoir, if one exists. A right is allowed to refill storage only in its primary reservoir, and only up to the storage capacity of the right. A stream flow depletion is then made to meet the target. If the available stream flow is greater than the target, the target stream flow depletion is taken from the available flow, and the computations continue on to the next right in priority order. If there is not enough available stream flow to meet the target, the additional amount is released from reservoir storage.

The permitted diversion amount for a type 1 right is given priority over refilling of reservoir storage when the amount of water available is insufficient to supply both. The computations to replenish storage in the primary reservoir are based on the total capacity associated with that water right. Subsequent junior rights may have storage capacities that are higher than the right in question, but this extra storage capacity is ignored by the current right in refilling storage.

Computations for a type 2 right are identical to a type 1 right except a type 2 right is not allowed a primary reservoir in which to replenish storage. The target depletion for a type 2 right is simply the permitted diversion amount. Although a type 2 right cannot refill storage, it can meet its diversion requirement from releases from storage from one or more reservoirs.

The target requirement for a type 3 right is computed identically to a type 2 right, but a type 3 right is not allowed to make a stream flow depletion. The available stream flow is by definition zero. The permitted diversion is treated as an additional amount to be released from system reservoirs. For water right types 1, 2, and 3, diversion shortages are calculated as the difference between the permitted diversion amount and the amount of the diversion target actually met.

With a type 7 right, a target is computed just like for a type 1 diversion. The simulation computations for a type 7 right are identical to a type 1 right except for the use of this target. With a type 7 right, the target replaces the total storage capacity at top of conservation from the *WS* record field 3 as long as the target does not exceed the *WS* record capacity. In any month in which the computed target exceeds the conventional *WS* record storage capacity, the target is ignored and the computations are identical to a type 1 right with zero diversion.

Reservoir Storage

Reservoir storage parameters are provided on the storage *WS* record associated with a water right *WR* record or an instream flow *IF* record if one of the storage options (*IFM(IF,3)* options 3 or 4) is activated. Any number of water rights can be associated with a single reservoir. Any number of reservoirs may also be associated with a single water right. However, a right may include a storage capacity to be refilled in only one reservoir, called its *primary* reservoir. Secondary reservoirs supply water use requirements but are not refilled by the right. The *WS* record includes the total storage capacity volume at the top of conservation pool and at the top of the inactive pool. Each individual water right associated with a reservoir has its own conservation and inactive capacities. Reservoir operations are defined by water right type specified on *WR* records and rules specified on operating rules *OR* records along with parameters on *WS*, *HP*, and other records.

The storage capacity at the top of conservation pool specified in *WS* record field 3 (or the alternative storage target for a type 7 right if less than *WS* record field 3 capacity) defines:

1. The pool from which that right can divert or release water. The right has access to the volume of water stored above its top of inactive pool and below its top of conservation pool storage levels. (Applicable for water right types 1, 2, 3, 4, 5, 6, and *IF* rights.)
2. The total cumulative capacity to which the reservoir can be refilled under the priority of that water right, assuming the reservoir has been drawn down in current and previous months and stream flow is now available for refilling. (Types 1, 5, 7 only.)

In the simulation, a water right can make no releases or diversions from its inactive pool. The reservoir storage level is allowed to fall below the top of inactive pool only due to evaporation.

SIMD allows gated or ungated flood control or surcharge storage capacity above the top of conservation pool to be included in the simulation, as described in the *Daily Manual*. However, *SIM* has no features for modeling flood control operations. In *SIM*, when a reservoir is full to the storage capacity defined by *WS* record field 3, outflow equals inflow.

Storage Capacity Versus Surface Area and Elevation Relationships

A storage volume versus water surface area relationship is provided as input for each reservoir for use in the net evaporation-precipitation computations. The net evaporation-precipitation volume for a given month is the computed average water surface area during the month times the appropriate net evaporation-precipitation depth.

Two optional formats are provided for inputting a reservoir storage volume versus surface area relationship. A table of storage volume versus surface area can be inputted on *SV/SA* records. The model applies linear interpolation to the table to determine the area corresponding to a computed storage volume. Alternatively, values of the coefficients *a*, *b*, and *c* can be provided on the *WS* record for use in the following equation incorporated in the model:

$$A = aS^b + c \quad (4.1)$$

where *S* and *A* denote reservoir storage volume and surface area. Typically, storage volume versus surface area tables are provided on *SV/SA* records for major reservoirs. These data are usually readily available for large reservoirs. A generic set of coefficients (*a*, *b*, *c*) for Equation 4.1 may be developed from data available for a few representative small reservoirs and then applied to numerous smaller reservoirs for which storage-area data are not available.

A water surface elevation versus storage volume table is provided on *PE/PV* records for any reservoir associated with hydropower for use in determining head. A *PE/PV* record elevation-volume table may also be input for reservoirs without hydropower to tabulate water surface elevations for information purposes.

Monthly Varying Limits on Storage Capacity

The monthly varying storage capacity option is motivated primarily by seasonal reallocations of storage capacity between flood control and water supply in multiple-purpose

reservoirs. Seasonal rule curve operating rules consist of varying the top-of-conservation pool or other designated pool levels with season of the year. Probably the most common use of seasonal rule curve operations is in allocating storage capacity in multiple-purpose reservoirs between flood control and conservation pools, based on seasonally varying characteristics of water supply and flood risk. The flood control pool consists of storage capacity above the designated top of conservation pool elevation that is kept empty except during and following major flood events. The bottom of the flood control pool coincides with the top of the conservation pool. A seasonal rule curve consists of varying the specified top of conservation pool elevation over the year.

Monthly varying upper limits on reservoir storage capacity are specified on *MS* records. A storage capacity limit is specified for each of the 12 months of the year. The monthly storage *MS* record supplements the *WR*, *WS*, and *OR* records. Reservoirs are refilled to the capacities specified on *WS* records. Multiple *WR* and *WS* records, representing refilling storage capacity to various levels with different priorities may be associated with a single reservoir. Likewise, multiple diversion rights may obtain water from a single reservoir or multiple-reservoir system. The monthly storage option simply places a limit on the maximum storage in a reservoir for each of the 12 months of the year. Reservoirs are filled to the capacities specified on the *WS* records subject to the constraint of not exceeding the limits specified on the *MS* records.

The monthly varying limits on storage capacity (*MS* record) option is reflected in the simulation in two ways.

1. Each month, prior to the water rights computation loop, the beginning-of-period storage content of each reservoir is limited to the capacity specified on the *MS* records. If the end-of-period storage content from the previous month exceeds the capacity limit, the excess water in storage is released back to stream flow, subject to an optional maximum release capacity limit specified on the *MS* record. The optional release capacity limit may result in longer than one month being required to lower the seasonal pool level. The spill from lowering the pool level is treated identically to the inflows entered on *CI* records. The flow at the control point of the water right is increased by the amount of the spill. The stream flow at all downstream control points is increased by the amount of the spill adjusted for channel losses.
2. As reservoir storage is refilled in the water rights loop, the end-of-period storage content is constrained to not exceed the specified monthly varying maximum storage limit.

Reservoir Storage Content at the Beginning of the Simulation

By default, all reservoirs are assumed to be full to their maximum storage capacity at the beginning of the simulation. If not specified otherwise, reservoirs start the simulation full. A less than capacity beginning storage content for any reservoir may be specified on its *WS* record. Another set of beginning-ending storage (BES) options is described in Chapter 6 that allows the storage at the beginning and end of the simulation to be the same, representing an infinite recycling of the hydrologic period-of-analysis. Any other beginning storage can also be defined in a BES file.

Reservoir/River System Operations

With a little ingenuity and imaginative creativity, *SIM* water right options may be integrated in a variety of ways to model a comprehensive range of reservoir system operating scenarios.

Operating rules may range from very simple to very complex. Considerable flexibility is provided to simulate complex system operations by combining:

- a storage *WS* record for each reservoir associated with a water right defining storage capacities and operating parameters
- water right features associated with *WR* and *IF* records and auxiliary *SO*, *ML*, *TO*, *LO*, *FS*, *CV*, *BU*, and *TS* records including the river/reservoir system operating rules specified by categorizing a right as type 1, 2, 3, 4, 5, 6, or 7 and target setting options including storage targets
- drought indices allowing diversion, instream flow, hydropower, and storage targets to be specified as a function of storage content (*DI/IS/IP/IM* records)
- monthly varying limits on storage capacity (*MS* record)
- reservoir release capacity (*OR* record) which may be varied with flow conditions (*FS* and *CV* records which connect to target setting records)
- multiple reservoir system operating rules (*OR* record)
- multiple owners sharing storage in the same reservoir (*EA* record)
- hydroelectric power features of a project (*HP* record)
- priority sequence circumvention options (*PX* records)

Most aspects of modeling water rights covered throughout this chapter are relevant to reservoir system operations. Later sections of this chapter focus specifically on (1) multiple rights associated with the same reservoir and (2) multiple reservoirs associated with a single right. *SIMD* flood control operations are covered in the *Daily Manual*.

Iterative Reservoir Volume Balance Computations

Reservoir water budget computations are performed within *SIM* for each individual water right that has reservoir storage, within the water right priority sequence, which is repeated within the monthly time step sequence. The following three volumes are computed simultaneously:

- end-of-month reservoir storage volume
- reservoir outflow (releases and withdrawals) volume during the month
- net water surface evaporation less adjusted precipitation volume during the month

Since, the monthly storage, outflow, and net evaporation volumes are all dependent on each other, an iterative computational algorithm is required.

Net water surface evaporation-precipitation is discussed in the preceding Chapter 3. The net evaporation volume is computed each month by multiplying a net evaporation depth times the average water surface area determined as a function of storage volume. The reservoir surface area is a simple average of the areas at the beginning and end of the month. The beginning-of-month area is determined as a function of the known beginning-of-month storage volume. However, the unknown end-of-month reservoir storage volume depends upon the net evaporation volume. Thus, the estimated end-of-month reservoir surface area changes during the course of

iterative computations along with the improvements in the end-of-month storage volume and net evaporation volume estimates.

The stop criteria for the iterative algorithm is based on comparing successive computed end-of-month storage volumes. The computations stop if the difference between successive end-of-month storage volumes is less than either 0.1 unit (acre-foot) or 0.01 percent. The computations also stop upon completion of a maximum of 50 iterations, with a warning message written to the message file that the 50 iteration maximum was reached and the last storage computed was adopted.

As discussed later in this chapter, hydroelectric energy generation is a function of head as well as discharge. Average head is a function of the end-of-month storage, which is also being computed, as well as the known beginning storage. The hydropower routine iteratively activates the iterative reservoir routine described above in its own iterative routine to meet an energy target.

The following previously-computed known amounts are provided to the *SIM* routine that performs the iterative computations to determine reservoir outflow, net evaporation, and end-of-month storage volumes for a particular reservoir for a particular water right.

- beginning-of-month storage
- stream inflows into the reservoir from stream flow depletions for senior rights
- inflows into the reservoir from releases from upstream reservoirs for senior rights
- available stream flow still remaining for appropriation by the current water right
- outflows (releases and diversions) for other more senior water rights
- outflow target for the current water right

The reservoir volume balance computations like other aspects of *SIM* must be understood within the framework of the priority sequence. Stream flow depletions, releases from upstream system reservoirs, and diversions and releases from this reservoir are accumulated in memory and incorporated into the water budget computations associated with other more junior rights at the same reservoir. In the water right priority sequence simulation, the water accounting computations for a particular water right include consideration of the diversions and releases at the same reservoir previously determined for more senior rights. However, the evaporation and end-of-month storage previously computed for the senior rights at the reservoir is not considered.

With multiple rights at the same reservoir, *SIM* computes the total net evaporation volume along with end-of-month storage content from scratch for each water right in turn in the priority sequence, not the incremental decrease or increase in evaporation. The actual correct evaporation volume and end-of-month storage for a reservoir are the amounts computed for the last right in the priority sequence at the reservoir. However, intermediate evaporation and end-of-month storage estimates computed during the priority sequence are used in determining the amount of water available from reservoir storage for individual rights. The determination of the amount of water available to a particular water right from reservoir storage is based on information currently known at that point in the priority sequence. Likewise, for hydropower rights, head available to generate hydroelectric energy is based on information currently known at that point in the priority sequence. Evaporation and storage volumes are written to the output file for types 1 and 7 and hydropower (types 5 and 6) rights but not for types 2 and 3 rights.

Water Supply Diversions

A monthly water supply diversion target is determined by combining an annual diversion amount from a *WR* record with the appropriate monthly distribution factor from an *UC* record. The water use type on the *WR* record connects the diversion right with the appropriate monthly use coefficients. If a use type is not entered in field 4 of the *IF* or *WR* record, the default of a constant uniform distribution (1/12 of total in each month) is adopted. An entry of *NDAYS* distributes the annual target in proportion to the number of days in each month (28, 30, or 31 days/month).

As discussed later in this chapter, a variety of other options may be employed in setting a diversion target. A series of diversion targets that vary annually as well as monthly may be entered on target series *TS* records. The drought index option (*DI* record) allows diversion targets to be adjusted as a function of storage content in selected reservoirs. A multiplier factor, as a percentage, is determined by combining the beginning-of-month storage with a storage versus multiplier factor relationship defined by *IS/IP* records. The diversion target can also be modified as a function of stream flow, storage, and specified upper and lower limits by options controlled with supplemental options *SO*, target options *TO*, cumulative volume *CV*, and flow switch *FS* records.

Intermediate targets may be computed with the various target setting options. Only one target and shortage are included in the simulation results recorded for each water right for each period. In the case of adopting multiple options resulting in multiple intermediate targets, *SO* record field 9 allows selection of which diversion target and shortage to include in the output file.

A diversion shortage is declared any time the diversion target cannot be fully met. A diversion shortage is computed as the monthly target described in the preceding paragraphs less the computed actual diversion amount as limited by water availability.

In the *SIM* simulation, in the water rights priority loop, diversion requirements are satisfied to the extent allowed by available stream flow and reservoir storage. The priority number sets the seniority of the diversion relative to other rights. A diversion requirement may be run-of-river with zero storage. Alternatively, a diversion requirement may be met by stream flow supplemented by releases from one or more reservoirs.

Return Flows

Return flows can represent water discharged back into the stream after use, such as municipal and industrial wastewater treatment plant effluent or irrigation return flows. Return flows can also represent water transported through conveyance facilities such as canals, pipelines, and pumping plants from other control points which may be located any place. The control points of origin and destination of the diversion return flow can be located in different river basins. Intrabasin or interbasin transfers may be simulated in this manner. Alternatively, such transfers of water may also be modeled as a type 4 right (*WR* record field 6) or by using the alternate control point (*SO* record), pipeline (*OR* record), or constant inflow (*CI* record) options described elsewhere in this chapter. Transient right XP option 1 on the *PX* record allows return flows computed as a function of actual diversion amounts to have a priority that is different than the diversion. Return flow priorities affect the order in which other water rights have access to the return flow.

Return flows from water uses supplied by groundwater sources are often modeled as constant inflows on *CI* records rather than using the *WR* record return flow options described below. *CI* record flows are discharged at the beginning of the priority sequence. The previously discussed type 4 right allows return flows from groundwater to be assigned any priority.

Return flows are computed in *SIM* as a user-specified fraction of computed actual (rather than target) diversion amounts. A diversion return flow can reenter at any user-specified control point, which could be located downstream or upstream of the diversion location or on a different stream. The return flow factor and location are part of the water right *WR* record input data.

Timing of return flows is also a user-specified option. The return flows may be returned during the same month as the water right diversion or during the next month. Since water rights are considered in priority order, the return flows associated with a junior water right will not affect the water available to a senior right unless the return flow is carried over to the next month. *PX* record *XP* option 1 allows return flows to have a priority that is different than the diversion.

Return flow specifications provided on the *WR* record for each water right include the return flow factor, the control point location to which flows are returned, and whether return flows occur in the same month as the diversion or the next month. Return flows are computed in *SIM* by multiplying a computed diversion by a return flow factor, which may be either a constant specified on the *WR* record for the water right or optionally a set 12 monthly return flow factors specified on *RF* records associated with a specified type of water use. The variable *RFMETH* in *WR* record field 7 specifies the return flow method adopted for the water right as follows.

- 0 Default *RFD* from *JO* record field 15 is adopted. Option 1 is the *RFD* default.
- 1 A constant return flow factor *RFAC* is specified in *WR* record field 8. The return flow occurs in the same month as the diversion.
- 2 A constant return flow factor *RFAC* is specified in *WR* record field 8. The return flow occurs in the next month after the diversion.
- 3 An alphanumeric identifier *RFIDWR* is specified in *WR* record field 8 which connects the water right to a set of 12 monthly return flow factors input on *RF* records. The return flow occurs in the same month as the diversion.
- 4 An alphanumeric identifier *RFIDWR* is specified in *WR* record field 8 which connects the water right to a set of 12 monthly return flow factors input on *RF* records. The return flow occurs in the next month after the diversion.

Options 3 and 4 require that a set of 12 monthly return flow factors be input on *RF* records. Identifiers input in the *WR* and *RF* records connect the water rights to the appropriate return flow factors. Options 1 and 2 both include a value for *RFAC* on the *WR* record, so *RF* records are not required. If the *RFAC* field is left blank, there is no return flow.

Hydroelectric power releases through turbines are also treated as return flows using the same options applied to diversions. The default for hydropower is to return 100 percent of the hydropower release at the next downstream control point during the same month as the release. However, the next month option, return to another control point, and the other options available for diversions are computationally applied to turbine flows in the same manner.

Other Inflows and Outflows

Stream flow adjustments may be specified as either *FA* or *CI* records. Constant inflow *CI* records consist of 12 inflows or outflows, for the 12 months of the year, which are repeated each year. Flow adjustment *FA* records are used to input multiple-year sequences of inflows or outflows, with the monthly flows varying between years. The adjustments from the *FA* or *CI* records are applied by the *SIM* model in essentially the same manner. As discussed in the *Hydrology Manual*, program *HYD* provides more flexible options for applying *CI* and *FA* record adjustments, which includes the *SIM* methodology discussed below and variations thereof.

The most common applications of *CI* records are to model (1) return flows not otherwise included in the return flow options, such as return flows from water supply withdrawals from groundwater aquifers and (2) interbasin transfers of water to the control point. *FA* records have been used to enter flow adjustments representing interactions between groundwater and stream flow associated with aquifer pumping. In general, *CI* or *FA* records could also be used to model diversions not otherwise included in the water rights, channel losses not otherwise modeled in the channel loss computations, or other flow features.

The following discussion focuses on *CI* record adjustments but is also pertinent to *FA* record adjustments which are described in the *Users Manual*. The constant inflow/outflow (*CI* record) option allows input of 12 flows, for the 12 months of the year, associated with a specified control point. An outflow is entered as a negative value of inflow. The constant inflows are added to the flows at the control point designated on the *CI* record and at all control points located downstream. If channel loss factors are input on pertinent *CP* records, the *CI* record inflows/outflows are adjusted by channel losses at downstream control points.

Sequences of inflows for each control point provided as input on *IN* records typically consist of naturalized stream flows. The next-period return flow option allows diversion return flows to be added to the naturalized flows for the next month after the diversion. At the beginning of the monthly simulation loop, prior to performing the water allocation computations, *SIM* combines the inflows/outflows from the *CI* records with the naturalized flows from the *IN* records and return flows from the previous month. The constant inflows/outflows are added after the optional negative incremental flow adjustments.

A constant monthly outflow may be input as a negative value on a *CI* record. Negative inflows are not allowed to reduce the total stream flow to below zero. If an outflow (negative inflow) is greater than the combined *IN*-record naturalized flow plus return flows from the previous month, the combined total of all three components is set equal to zero. The reduced value of negative inflow at the designated control point is carried downstream. The negative *CI*-record inflow is also restricted from reducing the total flows at the downstream control points to below zero. A *CI*-record outflow (negative inflow) is essentially equivalent to a diversion that is senior to all the water rights on the *WR* and *IF* records.

Hydroelectric Energy Generation

Hydroelectric energy production rights are similar to diversion rights in *WRAP-SIM*. Both hydropower (types 5 and 6) rights and diversion (types 1, 2, and 3) rights are activated with a water

right *WR* record. An energy generation target is entered on the *WR* record for a hydropower right. Reservoir storage and hydropower operation information is specified on *WS* and *HP* records. A reservoir storage volume versus water surface elevation table (*PV/PE* records) and constant tail-water elevation (*HP* record) or tail-water elevation versus discharge table (*TE/TQ* records) are input to allow the model to compute head.

Hydroelectric power is generated with all water that is available to the turbines in the priority-sequenced simulation computations, which includes reservoir releases and pass-through flows associated with senior water supply rights, available unregulated stream flows, and releases from reservoirs made specifically to meet the hydropower generation target. If multiple hydropower rights are assigned to the same reservoir/hydropower project, the energy generation associated with each right is the total energy that can be generated with all the water available at that point in the priority sequence. Unlike multiple diversions at the same reservoir which can be summed to obtain a total diversion amount, each of the hydropower energy production amounts are already a cumulative total. Thus, energy production associated with multiple hydropower rights at the same reservoir cannot be added.

Energy generation target and shortage amounts are written to reservoir/hydropower project and/or water right output records in the *SIM* output OUT file and tabulated with *TABLES*. Energy generation target and shortage amounts associated with individual hydropower rights are also stored in a HRR file and reorganized as tables with *TABLES*. If only one hydropower right is associated with a particular reservoir/hydropower plant, the energy amounts are the same on the reservoir/hydropower and water right output records. With multiple hydropower rights at the same reservoir/hydropower project, the multiple water right output records contain the cumulative energy amounts associated with each water right. The reservoir/hydropower project output record shows the cumulative energy amount associated with the most junior hydropower right at the reservoir.

For each period of the simulation, the energy production target is met as long as sufficient water and head is available from stream flow and reservoir storage. An energy shortage occurs if sufficient water is not available to meet the user-specified energy requirement. The model also computes secondary or surplus energy. Secondary energy represents additional energy, above the specified energy target, that potentially could be generated by passing reservoir releases for downstream diversions through the turbines. Only reservoir releases for water rights senior to the hydropower right are considered in computing secondary energy. Secondary energy is treated by the model as a *negative* energy shortage. No releases from storage or stream flow depletions are made if previous releases for senior rights are sufficient to meet or exceed the energy requirement.

Power generation may be constrained by both an optional turbine discharge capacity and a maximum monthly energy amount specified on the *HP* record. Minimum reservoir storage levels allowing power generation are also specified.

Flows through hydroelectric power turbines are returned to the river computationally in the same manner as water supply diversion return flows. Return flow options specified by *WR* record fields 7–9 (*RFMETH*, *RFAC*, *RFIDWR*, *RCP*) are applied to hydropower releases the same as to diversions. The default is to return 100 percent of the turbine flow at the next downstream control point below the control point of the water right during the same month as the release. However,

hydropower releases may contribute to downstream flows optionally either the same or next month. The flows may enter the river at any specified control point.

Input Data for Hydropower Rights

A hydroelectric energy generation right is represented by the following input data:

- control point location [*WR* record field 2]
- annual energy generation target [*WR* record field 3]
- set of 12 monthly energy target distribution factors [*WR* record field 4, *UC* records]
- drought index for varying energy target as a function of reservoir storage [*DI/IS/IP* records]
- optional series of monthly energy generation targets that vary between years [*TS* record]
- priority number [*WR* record field 5]
- water right type [*WR* record field 6]
- active and inactive reservoir storage capacities [*WS* record fields 3 and 7]
- parameter *LAKESD* for diversion rights indicating whether diversions can be released through hydropower turbines and thus contribute to power generation [*WS* record field 11]
- plant efficiency factor [*HP* record field 2]
- tail-water elevation [*HP* record field 3] or tail-water rating table [*TE/TQ* records]
- turbine inlet invert elevation [*HP* record field 4]
- turbine discharge capacity [*HP* record field 5]
- maximum limit on secondary energy generation [*HP* record field 6]
- reservoir storage versus water surface elevation table [*PV/PE* records]
- multiple-reservoir system operating rules [*OR* records]
- turbine discharge return flow specifications [*WR* record fields 7, 8, 9]
- multiplier factor *POWFCT* [*XL* record field 7]

Energy Equation and Multiplier Factor

Hydroelectric energy computations are based on the following equations:

$$E = P t \tag{4.2}$$

$$P = \gamma Q H e \text{ (unit conversion factors)} \tag{4.3}$$

$$E = \gamma Q H e t \text{ (unit conversion factors)} = Q H e t (POWFCT) \tag{4.4}$$

where the terms are defined with examples of typical units in brackets as follows:

E – energy generated [Watt-hour (W-hr) = 3,600 Newton-meters = 2,650 ft-lbs;
megaWatt-hr (MW-hr) = 1,000,000 W-hr = 1,000 kiloWatt-hr (kW-hr)]

- P – power generated [Watt (W) = Nm/second; MW = 1,000,000 W = 1,000 kW;
horsepower = 550 ft-lb/s = 0.7457 kW]
- γ – unit weight of water [lb/ft³, kN/m³]
- Q – discharge through turbines during time period [ac-ft/month; 10³ m³/month]
- H – head [feet, meters]
= mean reservoir water surface elevation for period minus tail-water elevation
- e – plant efficiency [dimensionless]
- t – time period (one month)

POWFCT = power factor used in *WRAP-SIM*

In the *SIM* model, hydroelectric energy (E) produced is represented as:

$$E = Q H e t (POWFCT) \quad (4.5)$$

where: $POWFCT = \gamma$ (unit conversion factors) (4.6)

POWFCT is a multiplier factor that reflects unit conversions and the unit weight of water. Values of *POWFCT* for several alternative sets of units are tabulated in Table 4.2 and may be computed for any other set of units. *SIM* uses a default *POWFCT* of 0.0010237 corresponding to the units shown in the last column of Table 4.2. Thus, the default *POWFCT* = 0.0010237 automatically used by *SIM* is appropriate if the variables are expressed in the following units:

$$POWFCT = 0.0010237$$

energy (E) in megawatt-hours (MW-hrs)
discharge (Q) in acre-feet/month
head (H) in feet

If other units are adopted, a value for *POWFCT* must be entered in field 7 of the multiplier factor *XL* record.

Table 4.2
Hydropower Factor for Alternative Sets of Units

specific weight γ	9.80 kN/m ³	9.80 kN/m ³	9.80 kN/m ³	62.4 lb/ft ³	62.4 lb/ft ³	62.4 lb/ft ³
units for:						
volume/period, Q	m ³	1,000 m ³	10 ⁶ m ³	acre-feet	acre-feet	acre-feet
head, H	meters	meters	meters	Feet	feet	feet
energy, E	kN-m	kW-hrs	MW-hrs	ft-lbs	kW-hrs	MW-hrs
<i>POWFCT</i>	9.80	2.7222	2.7222	2,718,144	1.0237	0.0010237

The model default of *POWFCT* = 0.0010237 with energy in megaWatt-hours (MW-hrs) is computed as follows for illustrative purposes.

$$E = \gamma Q H e t (\text{unit conversion factors}) = Q H e t (POWFCT) =$$

$$\left(62.4 \frac{\text{lbs}}{\text{ft}^3} \right) \left(\frac{\text{ac-ft}}{\text{month}} \right) (\text{feet}) (\text{month}) \left(\frac{43,560 \text{ ft}^3}{\text{acre} \cdot \text{feet}} \right) \left(\frac{\text{m}}{3.281 \text{ ft}} \right) \left(\frac{\text{N}}{0.2248 \text{ lbs}} \right) \left(\frac{\text{hour}}{3,600 \text{ s}} \right) \left(\frac{\text{MW}}{1,000,000 \text{ W}} \right)$$

$$E = Q H e t (0.0010237)$$

As noted in Table 4.2, the value for *POWFCT* is 2.7222 if the following units are adopted: flow volume for period *t* in 1,000 cubic meters (10³ m³), head in meters (m), and energy in kiloWatt-hours (kW-hrs).

$$E = \left(9.80 \frac{\text{kN}}{\text{m}^3} \right) \left(\frac{10^3 \text{ m}^3}{\text{month}} \right) (\text{meters}) (\text{month}) \left(\frac{\text{hour}}{3,600 \text{ s}} \right)$$

$$E = Q H e t (2.7222)$$

POWFCT values for any other set of units can be determined in a similar manner.

System Operating Rules for Hydroelectric Power

Types 5 and 6 hydropower rights are analogous to types 1 and 3 diversion rights (*WR* record field 6). A type 6 right limits energy generation to releases from storage. Type 5 rights allow refilling of reservoir storage. With either type 5 or 6 rights, releases may contribute to downstream flows optionally either the same or next month. Return flow options provided by the *WR* record are applied to hydropower releases the same as to diversions. The default is to return 100 percent of the hydropower release. Since type 5 and 6 rights are not constrained by instream flow rights, reservoir storage should be refilled with a separate *WR* record that is subject to instream flow requirements.

Hydroelectric power production can be included in multiple reservoir system operations. Hydroelectric power can be generated only at a primary reservoir. Energy can be generated at a hydroelectric plant as a type 5 or 6 right using flows from releases from multiple reservoirs. A run-of-the-river hydropower right is modeled as a type 5 water right with the total storage capacity equal to the inactive capacity.

By default, all diversions and releases from a reservoir contribute to power generation for junior hydropower rights at the reservoir, unless otherwise specified. When a non-hydropower water right diversion is met from a primary reservoir and/or secondary reservoirs, the water is released either through the reservoir hydropower turbines or directly from the reservoir pool, not passing through the turbines, depending upon the input specifications (*WS* record field 11). The hydropower release is computed as the additional release amount needed to meet the energy target, considering all releases for more senior rights that pass incidentally through the turbines.

Because the energy produced is a function of both the flow through the turbines and the average head on the turbines, hydropower rights are handled differently than diversion rights in regard to assumptions regarding refilling reservoir storage. The non-hydropower convention of ignoring storage above the storage capacity of the water right in a multiple-right reservoir is not

applicable to hydropower. A type 5 hydropower right will make stream flow depletions and receive releases from secondary reservoirs to meet its energy requirement as well as refill storage up to its storage capacity. If the storage in the reservoir is above the capacity of the right, the right will make stream flow depletions and reservoir releases necessary to just maintain the storage level while meeting the energy requirement. The target stream flow depletion is computed as the additional water that must be passed through the hydropower turbines assuming that the end-of-period storage is either the water right storage capacity or the current storage level, whichever is higher, plus the amount needed to refill storage. The actual energy produced must be computed in an iterative manner if the reservoir is drawn-down by releases through the turbines since the monthly release volume required depends on head but head depends on the release volume.

Multiple Hydropower Rights at the Same Reservoir

Any number of hydropower rights may be associated with the same reservoir, but certain physical characteristics of the reservoir are fixed, remaining constant for all rights. The tables describing volume-area (*SV/SA* records), volume-elevation (*PV/PE* records), and tail-water discharge-elevation (*TQ/TE* records) relationships are fixed for a reservoir. These tables are provided only once for each reservoir. The turbine inlet capacity, turbine discharge capacity, and maximum limit on energy production are fixed by the first *HP* record read that is connected to the reservoir and cannot be changed between rights. However, each of the multiple hydropower rights assigned to a single reservoir has its own energy target and priority set by its *WR* and auxiliary records, own efficiency (*HP* record), and own inactive and total storage capacities (*WS* record).

The cumulative total energy generated at a reservoir/hydropower project is recomputed for each right. The energy value reported on a reservoir/hydropower record in the main OUT output file represents the energy produced by the most junior hydropower right at the reservoir. The intermediate values of energy for senior rights are recorded on OUT file water right output records and listed in the reservoir/hydropower HRR output file. The storage used in the computations is the current end-of-period storage for that reservoir. Junior rights associated with the reservoir may increase or decrease the storage amount, changing the energy actually produced at the reservoir.

Instream Flow Requirements

In WRAP, an *IF* record instream flow right sets a target minimum regulated flow rate at a control point location. The objective is to maintain regulated flows equal to or greater than the monthly instream flow targets. The units for instream flow targets employed in the computations are the same as the other flow rate terms in WRAP, such as acre-feet/month or other volume/month units. Instream flow requirements typically represent environmental flow needs for preservation and enhancement of ecosystems, fisheries, and wildlife habitat and but may also serve various other purposes such as recreation, aesthetics, water quality, and water supply.

The following alternative general strategies may be employed in establishing minimum instream flow targets for *IF* record water rights in the *SIM* and *SIMD* simulation models.

1. *IF* record and *WR* record targets are computed step-by-step within *SIM* or *SIMD* following the procedure outlined later in this chapter in the section entitled *Setting Diversion, Instream Flow, and Hydropower Targets*. The procedure begins with the annual target amount entered

in *IF* or *WR* record field 3 and progresses through the series of optional computational steps described later in this chapter.

2. Another alternative instream flow target setting option can be selected in *IF* record field 3 that is described later in this chapter in the section entitled *Environmental Flow Standards*. Hydrologic condition *HC*, environmental standard *ES*, and (for a daily *SIMD* simulation) pulse flow *PF* and pulse flow options *PO* records are employed to model *IF* record instream flow rights in the format of Senate Bill 3 (SB3) environmental flow standards.
3. Either the first or second strategies described above may be employed with *IF* record rights, or the two strategies can be combined. An initial instream flow target determined with the second strategy employing *HC*, *ES*, *PF*, and/or *PO* records may be adjusted following the first strategy listed above employing *TS*, *TO*, *SO*, *FS*, *CV*, *DI*, *IS*, *IP*, *IM* and/or other *SIM/SIMD* input records.

The strategies noted above are all applicable to either *WR* or *IF* record water rights. However, although generically applicable with *WR* record water rights, *HC*, *ES*, *PF*, and *PO* records are designed specifically for modeling environmental flow standards as *IF* record instream flow rights.

Instream flow targets are specified in a *SIM* input file using an instream flow *IF* record and supporting water use coefficient *UC*, drought index *DI/IS/IP/IM*, target options *TO*, supplemental options *SO*, flow switch *FS*, cumulative volume *CV*, target series *TS*, environmental standard *ES*, and/or hydrologic condition *HC* records. An *IF* record is required for each instream flow water right. The other optional auxiliary records activate various options.

With either of the strategies outlined above, any number of *IF* records may be input for a particular control point, with the next more junior instream flow target replacing the latest more senior target or optionally the largest or smallest controlling at different priorities.

Water allocation routines in *SIM* are based on user-assigned priorities for all rights, which include instream flow requirements as well as diversion, storage, and hydroelectric energy requirements. Instream flow requirements may be assigned to any or all control points. Any number of instream flow requirements (*IF* records) may be input for a particular control point, with the next more junior *IF* record target replacing the latest more senior target in the priority-based water rights loop sequence. Thus, as each water right is considered in turn based on priority, the only instream flow target at a control point constraining water availability is the last *IF* record target set based on priority. However, this instream flow target may be replaced by a more junior *IF* record instream flow target later in the priority loop.

Two types of actions may occur in the simulation in order to prevent or minimize failures (shortages) in meeting the minimum instream flow targets.

1. Constraints placed on the amount of stream flow available to diversion and storage rights, that are junior to an instream flow requirement, may result in these rights being curtailed to minimize shortages in meeting the instream flow target.
2. Releases from reservoirs identified by *WS* records associated with the *IF* record may be made specifically to meet instream flow requirements.

In the *SIM* water rights computation loop, with or without instream flow requirements, the amount of water available to a right is based on yet unappropriated flows at the control point of the right and at all downstream control points. Instream flow requirements add constraints limiting water availability based on regulated flow targets. Diversion and storage rights that are junior to an instream flow right may have the amount of water available to them constrained, thus resulting in curtailment of stream flow depletions for diversions and reservoir storage.

Reservoirs Associated with IF Record Rights

Junior diversion rights are curtailed and inflows are passed through junior upstream reservoirs to meet an instream flow requirement, regardless of whether or not storage rights (*WS* record) are attached to the instream flow right (*IF* record). Without *WS* records connected to the *IF* record, the releases each month through the outlet works of reservoirs associated with junior rights resulting from senior *IF* record rights do not exceed reservoir inflows that month. Only inflows are passed through reservoirs.

Reservoir storage *WS* records must follow the *IF* record in the *DAT* file if releases from storage in one or more reservoirs associated with the instream flow right are to be used to prevent regulated flows from falling below the minimum instream flow targets. Any number of reservoirs identified with *WS* records may be operated with releases from storage to maintain instream flow requirements at control points located at or downstream of the dams.

Releases from reservoir storage (*WS* and *OR* records) may be incorporated with instream flow rights (*IF* records) just the same as with type 2 diversion rights (*WR* records). However, *IF* record rights do not refill storage. Water right types are not specified on the *IF* record, but all *IF* record rights are equivalent to type 2 rights defined on the *WR* record. Reservoir releases are made as necessary to meet the target minimum regulated flow, but storage is not refilled. Type 1 *WR* record rights must be included in the dataset to refill storage in reservoirs.

Interactions Between Hydropower and Instream Flow Rights

Hydroelectric power releases contribute to downstream regulated flows. The algorithms in the computer code automatically prevent hydropower rights from being curtailed as a result of instream flow requirements. Hydropower rights ignore instream flow requirements. For hydropower reservoirs, storage and energy requirements may be entered as separate *WR* records, if necessary, so that the reservoir storage (type 1 right) is constrained by instream flow limits on downstream water availability, but the turbine releases (type 5 or 6 right) are not.

Hydropower releases increase regulated and unappropriated flows at downstream control points. However, a next-month return flow option allows hydropower rights to appropriate stream flow one month and return it to the stream the next. This could allow storage associated with hydropower to reduce rather than increase downstream flows in a particular month.

Special Conditions

Instream flow limits are normally compared to the total regulated flow at specified locations in determining water available to junior water rights. However, an option is activated

by *IF* record field 6 that allows the instream flow limits to be compared to regulated flows exclusive of reservoir releases made from upstream reservoirs to meet water rights requirements at locations further downstream. This option allows modeling of situations in which reservoir releases for other purposes are not given credit for contributing to instream flows between the dam and downstream point of diversion.

An option is activated by *SO* record field 13 that allows a water right to not be constrained by instream flow requirements. This option facilitates convenient assessment of the impacts of instream flow requirements on particular water rights.

Specification of Instream Flow Requirements

Monthly instream flow targets are set similarly as diversion and hydropower targets. An annual instream flow target amount from an *IF* record is combined with a set of 12 monthly distribution factors provided on *UC* records to develop monthly regulated flow targets. *TO* records allow the monthly target to be adjusted as a function of river flows or diversions. The *FS* record activates options that either adjust or switch the instream flow requirement on or off based on whether a total regulated flow volume accumulated over a specified length of time at a particular control point falls within a defined range. The instream target can also be set as a function of reservoir storage using *DI/IS/IP/IM* records. A time series of instream flow targets may be input on time series *TS* records.

A water right consists of either an *IF* or a *WR* record, which may be accompanied by other records providing associated information. The model-user combines one or more *IF* and/or *WR* records along with other records as necessary to model a particular water right permit or set of water management/use requirements. The instream flow *IF* record is similar to the water right *WR* record. In a *SIM* input file, *IF* and *WR* records are grouped together in any order. *IF* records may be grouped together and placed either before or after the *WR* records or interspersed between *WR* records. *UC*, *DI/IS/IP/IM*, *TO*, *SO*, *FS*, *CV*, *TS*, *WS*, and *OR* records are associated with *IF* records the same as with *WR* records.

The instream flow amount *AMT* from the *IF* record is handled differently in the simulation than the diversion amount *AMT* in the same field of the *WR* record. The instream flow amount is a target minimum regulated flow at a control point. Without an instream flow requirement, the amount of water available to each right in the priority sequence is based on yet unappropriated flows. The instream flow target adds another constraint, based on regulated flows, on the amount of water available to all the water rights with priority numbers junior to that of the instream flow requirement.

Types of Instream Flow Computations

The computational method associated with a particular instream flow requirement is specified as variable *IFM(IF,3)* in *IF* record field 8. *PASS2* entered in *JO* record field 14 allows a second pass to be activated regardless of *IFM(IF,3)*. Otherwise, the options are as follows.

0, 1 Junior rights are curtailed as necessary to meet the instream flow requirements during a single pass through the water rights loop. The minimum instream flow (regulated flow)

targets result in constraints on the amount of water available to junior rights. At any point in priority sequence, regulated flow reflects only the effects of senior rights.

- 2 Junior rights are curtailed as necessary to meet instream flow requirement during a second pass through the water rights loop. The first pass through the water rights loop is used to compute regulated flows and instream flow shortages without limiting the amount of water available for other rights. The second pass is made only if at least one instream flow failure (shortage) occurs during the first pass.
- 2 Junior rights are curtailed as necessary to meet instream flow requirements during both the first and second passes through the water rights loop.
- 3 Option 3 is the same as Option 1 except reservoir releases are used as necessary to meet instream flow requirements. Option 3 requires that a reservoir storage *WS* record follow immediately behind the *IF* record. The *WS* record may be followed by *OR* records.
- 4 Option 4 is the same as Option 2 except reservoir releases are used as necessary to meet instream flow requirements. Option 4 requires that a reservoir storage *WS* record follow immediately behind the *IF* record. The *WS* record may be followed by *OR* records.
- 4 Option -4 is the same as Option -2 except reservoir releases are employed as necessary to meet instream flow requirements.

Example - Set of Records Specifying Instream Flow Requirements

For purposes of illustrating the *WRAP-SIM* strategy for modeling instream flow requirements, the computations to result from the input records shown below are discussed. Only the portion of the input file relevant to instream flow requirements is shown.

```

various input records of various types
various UC records
UCseason      0      0      0      0      0      0.25
UC            0.5    0.25    0      0      0      0
UC irrig      0      0      0      0.1    0.1    0.3
UC            0.4    0.1      0      0.0    0.0    0.0
other UC records
various other types of records
IF  CP7      6000      19850501      2      IF1
IF  CP15     5200    season19720801  2      IF2
IF  CP7     12000      19910215      2      IF3
IF  CP12     1800      19880601      2      IF4
WR  CP12     7800    irrig19880601      0.25      WR7
WS  Res-A   125000      -1
IF  CP12      0      19880601      2      IF5
IF  CP7      9000      99999999      4      IF6
WS  Res-B   50000      -1
many other records of various types

```

Water is allocated to all *IF* and *WR* rights in turn, in priority order, as the simulation proceeds through the water rights loop for January of the first year. Instream flow requirement

IF2 at control point *CP15*, with a priority date of 1 August 1972 (19720801) is the most senior of the rights shown and therefore the first to be considered. Multiplying the annual instream flow target of 5,200 ac-ft/yr by a January distribution factor of 0.0 results in a January target of zero.

Instream flow requirement *IF1* at control point *CP7*, with a priority of 19850501 (1 May 1985), is considered next. The January instream flow target is 1/12 of 6,000 ac-ft/yr or 500 ac-ft/month. This 500 ac-ft/month regulated flow target serves as a constraint on the amount of water available to water rights with a priority junior to 1 May 1985.

Instream flow requirement *IF3*, with a priority of 19910215 (15 February 1991), raises the instream flow target at control point *CP7* from 500 ac-ft/month, set by *IF1*, to 1,000 ac-ft/month. Thus, all rights with a priority date between 1 May 1985 and 14 February 1991 are subject to an instream flow requirement at *CP7* of 500 ac-ft/month, and those with priority dates of 15 February 1991 or later are subject to an instream flow requirement of 1,000 ac-ft/month.

Rights *IF4*, *WR7*, and *IF5* at control point *CP12* all have a priority of 19880601 (1 June 1988). Multiple rights with the same priority number are considered in the order they are entered in the input file. *IF4* sets an instream flow target of 150 ac-ft/month, which constrains the amount of water available to water right *WR7*. *IF5* resets the instream flow target back to zero. Thus, the 150 ac-ft/month instream flow requirement at *CP12* affects only water right *WR7*.

Instream flow requirement *IF6* changes the minimum regulated flow target at control point *CP7* from 1,000 ac-ft/month, set previously by *IF3*, to 750 ac-ft/month. Since the *IF6* priority of 99999999 is junior to all other water rights, this target has no effect on the amount of water available to the other rights. If the regulated flow at *CP7* is less than 750 ac-ft/month, releases from reservoir *Res-B* will be made to increase it to 750 ac-ft/month, as specified by the *WS* record following the *IF* record for *IF6*.

Multiple IF Record Rights at the Same Control Point

Multiple *IF* records may be used to model a particular set of instream flow requirements. Any number of instream flow *IF* records can be connected to the same control point. As each *IF* record water right is considered in the priority loop, the target set by that *IF* record right is compared with the target previously set by the preceding *IF* record right in the priority sequence at the same control point. An option controlled by the parameter in *IF* record field 7 allows selection between three options. The default option 1 is for the junior target to replace the senior target. Options 2 and 3 are to adopt the larger or smaller of the two targets. This procedure of comparing the latest two targets computed in the priority loop can be applied to any number of *IF* records at the same control point.

Same IF Record Right Applied at All Control Points in a Stream Reach

The instream flow target defined by the *IF* record and its auxiliary records is repeated at all control points between the control points entered in *IF* record fields 2 and 14. If the optional *IF* record field 12 is blank, the instream flow requirement is applied only at the control point entered in the required field 2. The optional parameter *CP2* in *IF* record field 14 defines a stream reach extending from the control point specified in *IF* record field 2 downstream to *CP2*.

This reach may contain any number of control points. CP2 in *IF* record field 14 is the identifier of a control point located further downstream, with the exception that OUT entered in field 14 assigns CP2 as the outlet. The instream flow target is set at all control points in the reach.

Instream Flow Computations

IF record instream flow targets are set within the *SIM* water rights priority sequence in essentially the same manner as *WR* record diversion and hydropower targets, but the targets are used differently. *IF* record instream flow targets are minimum limits on regulated flows used in defining water availability for junior *WR* record rights. For each month of the simulation, the *SIM* instream flow routines perform the following tasks. The *IF* record field 8 *IFM(IF,3)* options for which the tasks are relevant are shown in parenthesis.

Setting the Instream Flow Target for the Month (Options 0, 1, 2, 3, and 4) *SIM* determines the monthly instream flow target following procedures outlined later in this chapter based on information entered on an *IF* record and optional *UC*, *DI/IS/IP/IM*, *TO*, *FS*, *CV*, *SO*, and/or *TS* records or information entered in environmental flow standard format on *HC* and *ES* records. An instream flow target is expressed in the same units as a diversion target, such as acre-feet/month or other volume/month units.

Writing Instream flow Shortages to the Output File (Options 0, 1, 2, 3, and 4) The instream flow requirement is a target minimum regulated flow. For a given month, at the completion of the water rights loop, the instream flow target for each *IF* record right is compared with the regulated flows at the appropriate control point to determine whether failures to meet the targets occur and to compute the shortage amounts. A shortage occurs when the regulated flow is less than the instream flow target. The shortage, in volume/month units, is the difference between the instream flow target and the regulated flow. Targets and shortages are written to the main *SIM* output OUT file. Program *TABLES* reads the *SIM* output file and builds instream flow shortage tables in the same manner as the other tables are developed.

Initial Pass through Water Rights Loop (Options 2 and 4) With the dual pass options 2 and 4 activated, in the initial pass through the water rights computational loop, regulated flow constraints are not placed on the amount of water available to each *WR* record water right. Thus, junior rights are not curtailed to prevent instream flow shortages from occurring. If one or more failures to meet instream flow targets occur, a second pass through the computational loop is made. If no failures to meet instream flow targets occur in the first pass, there is no second pass; the simulation proceeds to the next month. For options 2 and 4, the first pass through the water rights loop serves the following purposes.

1. A determination is made of whether or not failures to meet instream flow requirements occur if no other diversion and storage rights are curtailed. The second pass through the water rights loop described below occurs only if one or more failures to meet instream flow targets occur in the first pass. This guarantees that junior rights are not unnecessarily curtailed due to instream flow requirements, in those months in which all instream flow requirements can be met without curtailing junior rights.
2. The regulated flows reflecting all the water rights are determined in this first pass. These regulated flows are used in the second pass as a lower limit on the regulated flows used to

define water availability. This prevents junior rights from being curtailed more than necessary in those months in which instream flow requirements do constrain junior rights.

Second Pass through Water Rights Loop (Options 2 and 4) If instream flow shortages occur during the first pass through the water rights loop described above, a second pass is performed. In the second pass, instream flow requirements result in constraints on the amount of water available to all rights that are junior to the instream flow requirements, except hydropower rights. The constraints on water availability result in junior rights being curtailed as necessary to prevent or minimize instream flow shortages.

Within the priority-based water rights loop, an instream flow requirement establishes a minimum regulated flow target at a specified control point that results in a constraint on water availability for junior water rights. The regulated flow is compared with the instream flow target to determine the limit on water availability. The regulated flow constraint is incorporated in subroutine *AVALB* for computing the amount of water available to each right in the priority loop.

Intermediate regulated flows computed during the second pass, with a minimum limit set by the final regulated flows at the completion of the first pass, are combined with the instream flow requirements to determine the constraints on water availability. As each water right is considered in turn, the intermediate estimate of regulated flow reflects only the effects of more senior rights, since the junior rights have not yet been considered in the priority-based water rights loop. However, the algorithm in *SIM* limits the regulated flow during the second pass to not drop below the final regulated flow computed at the completion of the first pass.

Second Pass through Water Rights Loop (Options -2 and -4) *IF* record field 8 *IFM(IF,3)* options -2 and -4 in combination with *PASS2* from the *JO* record provide variations of the procedure allowing curtailment of junior rights in all months regardless of conditions and always requiring a second pass. These options provide capabilities for experimentation on the effects of the instream flow algorithms.

Single Pass through Water Rights Loop (Options 1 and 3) Options 1 and 3 involve only one pass through the water rights priority sequence simulation loop. The instream flow requirements result in constraints on the amount of water available to junior water rights.

Reservoir Storage for Meeting Instream flow Requirements (Options 3 and 4) Options 3 and 4 involve using releases from reservoir storage to meet instream flow targets. Options 3 and 4 consist of adding reservoir storage to options 1 and 2, respectively. A *WS* record must follow the *IF* record for an option 3 or 4 instream flow requirement. Multiple-reservoir operating rules *OR* records may follow the *WS* record as appropriate.

Instream flow shortages are determined in the water rights loop. Whenever the instream flow target exceeds the monthly regulated flow at a control point, a shortage is computed as the instream flow target minus the regulated flow. For an *IF* record right with reservoir storage (*IFM(IF,3)* option 3 or 4), the instream flow shortage is mimicked as a diversion right with return flow factor of 1.0. The 100 percent return flow occurs at the same control point as the dummy diversion (instream flow shortage). Thus, if an instream shortage occurs, a diversion target equal to the shortage is created, and the corresponding return flow factor is assigned a

value of 1.0. The *IF* record right is then processed through the water right computations just like a *WR* record right. The simulation results recorded in the *SIM* output file for *IF* record and *WR* record water rights can be compared in Table 5.3 of Chapter 5. The reservoir release, storage, and net evaporation volumes are non-zero for instream flow output records only for *IF* record rights with *IFM(IF,3)* option 3 or 4.

Regulated Flows and Instream Flow Targets

For a given month, water is allocated to each water right in turn, in priority order, in the water rights computational loop priority sequence. At the beginning of the water rights loop, the regulated flow at a control point is the summation of:

- the naturalized flows from the *IN* records
- return flows from the previous month if the next-month return flow option is used
- gains or losses from an optional *CI* record or *FA* record

During the water rights allocation computations, the regulated flows are diminished by stream flow depletions for diversions and refilling reservoir storage. The regulated flows may be increased by return flows from diversions from reservoir storage, hydropower releases, or upstream reservoir releases for downstream diversions. The intermediate regulated flows and unappropriated flows in effect, when a particular water right is considered in the priority-based water allocation computation loop, depend upon the effects of the more senior rights that have already been considered.

From the perspective of *WRAP-SIM*, an instream flow requirement is a target minimum regulated flow at a control point. Any number of *IF* records may be associated with a control point, allowing the target minimum regulated flow to change in the priority sequence as the various water rights are considered. An actual instream flow requirement is modeled by combining as many *IF* records as necessary. An instream flow shortage occurs if the regulated flow falls below a minimum flow target. *SIM* computes and outputs the monthly instream flow shortages for each *IF* record right.

Actions to Prevent or Reduce Instream flow Shortages

The following two approaches are incorporated in *WRAP* to model regulatory actions in maintaining instream flow requirements.

1. In the water rights loop, as each water right is considered in turn, a first step is to compute the amount of water available to the right. The instream flow target is a constraint on the amount of water available to junior *WR* record rights. Reductions in water availability may result in curtailment of stream flow depletions for meeting diversion requirements and refilling reservoir storage associated with these junior rights.
2. An instream flow right (*IF* record) may also have its own reservoir storage (*WS* record). Releases from storage are made as necessary to prevent or minimize instream flow shortages at downstream control points. The *IF* record right allows only releases, not refilling of storage. In the model computations, the instream flow shortage is converted to a dummy diversion with 100% return flow, which is then handled the same as a *WR* record diversion.

Single Versus Dual Passes through the Water Rights Computational Loop

Modeling the effects of instream flow requirements on the numerous other diversion and storage rights in a river basin is complicated by the combination of the following two considerations.

1. Available stream flow is allocated to water rights based on priorities. Thus, the water rights are considered in priority order in the water rights computation loop.
2. Diversion and storage rights may either increase or decrease the regulated flows at a control point. Diversions and refilling reservoir storage decrease regulated flows at downstream control points. Conversely, regulated flows may be increased by (1) return flows from diversions from storage, (2) hydropower releases, or (3) upstream reservoir releases for downstream diversions.

As discussed earlier, in the priority-based water rights computational loop, restrictions on water availability due to instream flow requirements may result in shortages in meeting diversion and/or storage requirements that are not necessary. For example, the regulated flows may have dropped below the target level, thus restricting water availability, when a particular diversion right is considered. Thus, the diversion right incurs a shortage. However, more junior rights considered later in the computations may result in return flows from diversions from reservoir storage that raise the regulated flow above the instream flow target. The sole purpose for performing two passes through the water rights computation loop is to address this complication.

IFM(IF,3) options 1 and 3 perform the water allocation computations during a single pass through the water rights loop. The instream flow shortages computed by this approach are accurate. However, diversions and refilling of reservoir storage associated with other rights may have been curtailed more than necessary to prevent or reduce instream flow shortages. The dual-pass approach of options 2 and 4 provides protection against erroneously over restricting the amount of water available to other water rights in the following two regards. However, they do not guarantee that junior rights are not over-restricted.

1. In the dual pass approach, the first pass is used to compute regulated flows without allowing instream flow requirements to restrict the amount of water available to junior rights. The second pass occurs only if the first pass results in one or more instream flow shortages. Thus, option 2 guarantees that junior rights are not affected in any month in which instream flow targets are met anyway without restricting the amount of water available to other rights.
2. At completion of the first pass, the regulated flows reflect the effects of all water rights, but the rights are unrestricted by instream flow targets. In option 2, these final first-pass regulated flows are used in the second pass to set a lower limit on regulated flows used in the water availability computations. This prevents junior rights from being curtailed more than necessary in those months in which instream flow requirements do limit the amount of water available to junior rights.

An erroneous instream flow shortage could possibly occur in a situation in which a diversion right actually increased regulated flows in the first pass but is curtailed in the second pass. Consider a diversion downstream of the instream flow target control point made from

releases from a reservoir located upstream. The reservoir release increases the regulated flow at the instream flow target control point prior to being diverted downstream. For purposes of reducing instream flow shortages, this particular diversion right should not be curtailed. The model-user can handle this situation by bracketing the *WR* record in the input file with *IF* records, with the same priority as the diversion right, that turn the instream flow requirement off and then back on again just before and after consideration of the *WR* record right.

The second pass *IF* record option could possibly cause irregularities in simulation results when used with various complex combinations of other *SIM* modeling features and thus should be applied cautiously. In general, the single pass options 1 and 3 should be adopted unless specific reasons are clearly identified warranting the more complicated dual pass options 2 and 4.

With *IFM(IF,3)* options 2 and 4, instream flow requirements are imposed only during the second pass through the water rights computation loop. Thus, another problem with options 2 and 4 is that the final unappropriated flows do not reflect instream flow requirements in those months in which all requirements are met without necessitating a second pass.

The only reason for the *IF* record dual pass options is to deal with the problems of senior rights not getting access to water made available by junior rights through same-month return flows from diversions from storage and same-month hydroelectric power releases and obtaining credit for contributions to meeting instream flow requirements at intermediate control points made by releases from upstream reservoirs to meet diversions at downstream locations. As previously discussed, *CI* record return flow, next-month return flow, and next-month hydropower options are typically adopted to deal with return flows and hydropower releases. Thus, the dual pass option is applicable primarily in situations involving senior *IF* record instream flow requirements located between a junior *WR* record right's reservoir and its downstream water supply diversion. The second pass options would be adopted to prevent unnecessary curtailments by other *WR* record rights located between the dam and diversion with priorities falling between the senior *IF* record right and junior *WR* record right.

The single-pass *IFM(IF,3)* options 1 and 4 are the recommended default standard. The more complicated two-pass *IFM(IF,3)* options 2 and 4 should be applied with caution and only if specific reasons warranting switching to the two-pass strategy are clearly identified.

Environmental Instream Flow Standards

The following two alternative approaches may be adopted for setting *IF* record instream flow targets. This section focuses on the first alternative listed below. The second is discussed later.

1. A -9 in *IF* record field 3 activates a target setting procedure that employs *HC*, *ES*, and *PF* records to model instream flow rights in the format of Senate Bill 3 (SB3) environmental flow standards. This is the topic of this section. This approach is designed specifically for *IF* record instream flow rights but can coincidentally also be applied to *WR* record water rights.
2. Either *IF* or *WR* targets are established through a step-by-step procedure that begins with the annual target amount entered in *IF* or *WR* record field 3, which is allocated to the 12 months of the year based on a set of monthly water use distribution factors specified in *WR* or *IF* record field 4. This is a standard approach routinely employed with *WR* and *IF* record rights.

When employed with an *IF* record instream flow right, either of the alternative strategies noted above result in computation within the *SIM* simulation of an instream flow target for the current month at the specified control point. This instream flow target may be adopted as the actual final target employed in the simulation. However, alternatively, this target can be treated as an initial quantity to be further adjusted by optional target-setting features controlled by *TO*, *SO*, *FS*, *CV*, *DI*, *IS*, *IP*, *IM*, *TS*, and/or other *SIM* input records. The target-building process may progress through a series of optional computational steps described later in this chapter.

For example, SB3 environmental flow standards may include requirements for freshwater inflows to bays and estuaries that include cumulative inflow volumes that may be modeled with *SIM* features activated by flow switch *FS* or cumulative volume *CV* records that are combined with the *ES* and *HC* record modeling features described in the following paragraphs.

Senate Bill 3 (SB3) Environmental Flow Standards

The Texas Instream Flow Program (TIFP) was authorized by the 77th Texas Legislature in 2001 through Senate Bill 2. The TIFP is jointly administered by the Texas Commission on Environmental Quality, Texas Parks and Wildlife Department, and Texas Water Development Board and consists of scientific and engineering studies to determine flow conditions necessary for supporting a sound ecological environment in the river basins of Texas [43].

Senate Bill 3 (SB3) enacted by the 80th Texas Legislature in 2007 established a new regulatory approach to provide for environmental needs through the use of flow standards developed through a stakeholder process culminating in TCEQ rulemaking. Water right permits in effect prior to the effective date of September 1, 2007 are not impacted. Only new water rights and water right amendments that are submitted after this date are subject to the new requirements established pursuant to the 2007 Senate Bill 3 [27].

The expanded regulatory process created by Senate Bill 3 results in determination of environmental flow needs and establishment of set-asides to satisfy the environmental flow needs. *Set-asides* refer to commitment of previously unappropriated water in the TCEQ Water Availability Modeling (WAM) System to meet specified environmental flow standards. Environmental flow standards (requirements) for particular locations in particular stream systems are defined in terms of flow regimes. Senate Bill 3 defines an environmental flow regime as: *A schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies.*

Environmental flow standards adopted by the TCEQ consist of a set of flow metrics and rules that vary seasonally with location and/or by hydrologic condition and that govern decisions to curtail junior rights to divert and/or store stream flows. Environmental flow requirements or standards are defined in terms of flow regimes that describe the magnitude, frequency, duration, timing, and rate of change of stream flows required to maintain a sound ecology. The SB3 process has adopted a framework recommended by studies performed pursuant to the SB2 TIFP that defines an instream flow regime that includes four components: subsistence flows, base flows, within-bank high flow pulses, and overbank high pulse flows [27, 43].

Subsistence flows occur during drought or very dry conditions. A primary objective of subsistence flow standards is to maintain water quality. Other objectives include ensuring that species populations are able to recolonize the river system after normal base flow rates return. Base flows represent the range of average or normal flow conditions without the effects of recent rainfall. A primary objective of base flow standards is to ensure adequate habitat conditions, including variability, to support the natural biological community of the river system.

High flow pulses are short duration, high magnitude but still within channel, flow events that occur during and immediately following rainfall storms. High flow standards are designed to maintain physical habitat features and longitudinal connectivity along the river channel. Overbank flows are infrequent, high magnitude flow events that exceed channel banks resulting in water entering the floodplain. The primary objectives of overbank flow requirements are to maintain riparian areas and provide lateral connectivity to the floodplain. Other objectives may include transporting organic matter to the main channel, providing life cycle cues for various species, and maintaining the balance of species in aquatic and riparian communities.

Information regarding SB3 environmental instream flow standards can be found at the following TCEQ website.

https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/eflows

This website provides convenient access to the environmental flow standards that have been adopted to date, which are published as Subchapters B through F of Chapter 298 of Title 30 of the Texas Administrative Code. Rules for the river systems listed in Table 4.3 are published as individual subsections of Chapter 298. Modifications to these existing standards and establishment of standards for additional regions and river reaches are expected in the future.

Table 4.3
River Systems with SB3 Environmental Flow Standards

River System	Priority Date	Number of			Inflows to Bay
		Gages	Seasons	HCs	
Sabine and Neches Rivers and Sabine Lake Bay	April 2011	10	4	0	0
Trinity and San Jacinto Rivers and Galveston Bay	April 2011	6	4	0	1
Brazos River and its Associated Bay and Estuary System	March 2012	19	3	3	0
Colorado and Lavaca Rivers and Matagorda and Lavaca Bays	Aug 2012	22	4	4	2
Guadalupe, San Antonio, Mission, and Aransas Rivers, and Mission, Copano, Aransas, and SA Bays	Aug 2012	17	4	3	2
Nueces River and Corpus Christi and Baffin Bays	Feb 2014	19	4	0	1
Rio Grande, Rio Grande Estuary, and Lower Laguna Madre	Feb 2014	4	3	4	0

The WAM priority date shown in the second column of Table 4.3 reflects the date of submission of recommended environmental flow standards to the TCEQ by formally constituted expert science teams. The third, fourth, and fifth columns of Table 4.3 show the number of USGS gage sites at which flow standards are established, number of seasons, and number of hydrologic conditions defined. Four of the seven river systems have additional requirements for flows into one or two bays as indicated in the last column of Table 4.3. The SB3 environmental flow standards for all of the river systems include subsistence, base, and high pulse flow components. Details of the standards vary between river systems and between sites in the same river system. However, in general the standards provide minimum target limits on subsistence, base, and high pulse flows that vary seasonally and in many cases with hydrologic condition.

Definitions of seasons and hydrologic conditions are summarized in Table 4.4 for the SB3 environmental flow standards noted in Table 4.3. Standards for five of the river systems are based on four seasons per year, and the other two river systems have three seasons. Seasons are defined a little differently for the upper versus lower Colorado River Basin.

Table 4.4
Seasons and Hydrologic Conditions for SB3 Environmental Flow Standards

River System	Seasons				Hydrologic Conditions Variable and Number
	Winter	Spring	Summer	Fall	
Sabine and Neches	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	none
Trinity and San Jacinto	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	none
Brazos	Nov-Feb	Mar-Jun	Jul-Oct	none	Palmer HDI (3)
Colorado and Lavaca	Nov-Feb	Mar-Jun	Jul-Aug	Sep-Oct	12-month flow (4)
	Dec-Feb	Mar-Jun	Jul-Aug	Sep-Nov	reservoir storage (3)
GSA	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	12-month flow (3)
Nueces	Dec-Mar	Apr-Jun	Jul-Aug	Sep-Oct	none
Rio Grande	Nov-Feb	Mar-Jun	none	Jul-Oct	12-month flow (4)

Three of the seven river systems have SB3 environmental flow standards that employ three hydrologic conditions (dry, average, wet). Two other standards add a fourth hydrologic condition. Hydrologic conditions are applied differently at different sites and may be different for subsistence, base, and high pulse flow components of the standards. Flow standards for three of the seven river systems do not consider hydrologic conditions.

Dry, average, and wet hydrologic conditions for different regions of the Brazos River Basin are defined based on the Palmer hydrologic drought index. The environmental flow standards for the Guadalupe, San Antonio, Mission, and Aransas Rivers, Rio Grande, and some regions of the Colorado and Lavaca Rivers define hydrologic conditions based on the total river flow at a defined measurement point during the 12 months preceding the beginning of the current season. The standards for other regions of the Colorado and Lavaca Rivers define hydrologic conditions based on the combined storage contents of specified major reservoirs. The details of the standards vary between river systems and measurement points in the same river system.

Simulating Environmental Instream Flow Standards

Hydrologic condition *HC*, environmental standard *ES*, and pulse flow *PF* and pulse flow options *PO* records are designed specifically to model *IF* record instream flow rights in the format of SB3 environmental flow standards. The *SIM* and *SIMD* *HC* and *ES* input records are described in Chapter 3 of the *Users Manual*. The *SIMD*-only *PF* and *PO* input records are described in Chapter 4 of the *Users Manual* and Chapter 6 of the *Daily Manual*. Modeling SB3 environmental flow standards is illustrated by daily water availability model (WAM) studies for the Brazos, Trinity, Neches, and Colorado River Basins [44, 45, 46,47]. Water right EFS-1 from the example in *Daily Manual* Chapter 8 is replicated below to illustrate the following discussion.

IF Camer	-99.	201203					EFS-1							
**														
HC Hemp	1 HI	1 M	J	N		0.0	1.5	2.5	-9.					
**														
ES SF501	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.
ES BASE1	110.	110.	140.	140.	140.	140.	140.	97.	97.	97.	97.	110.	110.	
ES BASE2	190.	190.	310.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	
ES BASE3	460.	460.	760.	760.	760.	760.	760.	330.	330.	330.	330.	460.	460.	
**														
PF 0 1	1080.	6680.	8	1	0	11	2	0	0	2	0	3		Winter,HC1,Camer
PF 0 2	1080.	6680.	8	3	0	11	2	0	0	2	0	0		Winter,HC2,Camer
PF 0 3	2140.	14900.	10	2	0	11	2	0	0	2	0	0		Winter,HC3,Camer
PF 0 1	3200.	23900.	12	1	0	3	6	0	0	2	0	0		Spring,HC1,Camer
PF 0 2	3200.	23900.	12	3	0	3	6	0	0	2	0	0		Spring,HC2,Camer
PF 0 3	4790.	38400.	14	2	0	3	6	0	0	2	0	0		Spring,HC3,Camer
PF 0 1	560.	28600.	6	1	0	7	10	0	0	2	0	0		Summer,HC1,Camer
PF 0 2	560.	28600.	6	3	0	7	10	0	0	2	0	0		Summer,HC2,Camer
PF 0 3	990.	55500.	8	2	0	7	10	0	0	2	0	0		Summer,HC3,Camer

Any negative number in *IF* record field 3 activates a target setting routine that employs *HC*, *ES*, *PF*, and *PO* records to model *IF* record instream flow rights in the format of SB3 environmental flow standards. With this option activated, an *IF* record water right in a monthly *SIM* simulation input dataset consists of an *IF* record followed an optional *HC* record and an optional set of *ES* records. A set of 12 monthly flow limits ESQ(wr,es,m) in cfs are provided on each *ES* record. A set of *PF* and *PO* records can be added for a daily *SIMD* simulation.

The *HC*, *ES*, *PF*, and *PO* records serve the sole purpose of computing a minimum instream flow target for each month of a monthly *SIM* simulation or each day of a daily *SIMD* simulation. This set of records may be sufficient for setting the SB3 environmental flow target for an *IF* record right at a particular control point without needing other types of records. However, the options discussed in the next section of this chapter can be used to further adjust the final target in the manner applicable to *WR* right and *IF* record water rights in general.

Any number of *IF* record water rights and/or *WR* record water rights can be assigned to the same control point. Options for combining multiple *IF* record water rights are controlled by the entry in *IF* record field 7. All components of an environmental flow standard at a site can be modeled as a single *IF* record water right. However, multiple *IF* record rights can be employed as needed. For example, minimum subsistence and base flow limits could be specified as an *IF* record right, and minimum high flow limits could be modeled as another different *IF* record right at the same control point if the user wanted water right output records to be included in the simulation results for the two separate *IF* record water rights.

Alternative Sets of Minimum Instream Flow Limits

A SB3 environmental flow standard is modeled with an instream flow *IF* record, hydrologic condition *HC* record, and multiple environmental standard *ES* records. Each *ES* record provides a set of 12 monthly minimum instream flow limits [ESQ(wr,es,m)] that reflect seasonal variations over the twelve months of the year. Each *ES* record represents a specific flow regime component (subsistence, base, or high flow) and hydrologic condition. *ES* records can also optionally define seasonal flow targets without consideration of hydrologic condition.

A SB3 flow standard is normally modeled with an *IF* record, *HC* record, and several *ES* records for alternative combinations of flow regime components and hydrologic conditions. However, an *IF* record water right does not necessarily have to involve flow regime components and hydrologic conditions. For example, a simple *IF* record instream flow right with targets that vary over the 12 months of the year could be modeled with one *IF* record combined with one *ES* record or alternatively with one *IF*, one *UC*, and no *ES* record.

The flow quantities in the actual SB3 environmental flow standards are expressed as mean daily flows in cfs. Although other *ES* record options are provided, the *ES* record default is to enter the 12 monthly minimum flow limits in units of cubic feet per second (cfs). These are mean monthly flow rates in cfs. *SIM* automatically converts the flow rates in cfs to monthly volumes in acre-feet/month, considering the number of days [28 or 29 (leap year), 30, or 31] in each month. *SIMD* converts the mean flow rates in cfs to daily flow volumes in acre-feet/day. *ES* record parameters *ESAF* and *ESQX* activate options for using other alternative units.

The same *HC* and *ES* records are used for both monthly *SIM* and daily *SIMD* simulations. The multiple alternative sequences of 12 monthly minimum stream flow limit quantities (flow rates in cfs) are the same in either a monthly or daily simulation. Monthly volume limits are uniformly subdivided into daily volume limits in a daily simulation. However, the selection between subsistence versus base versus high flow limits each day depends upon daily regulated river flows in a daily *SIMD* simulation. Computed daily regulated stream flows differ from monthly regulated flows. A daily simulation is more accurate due to better representing within-month daily stream flow fluctuations. High flow pulse components are much more accurately modeled by *PF/PO* records and a daily *SIMD* simulation.

Hydrologic Conditions

The previously discussed actual SB3 environmental flow standards adopted to date include only three (dry, average, and wet) or four hydrologic conditions or in some cases no hydrologic conditions. *HC/ES* records allow up to nine hydrologic conditions to be defined if and as needed. Subsistence, base, and high flow regime components are each modeled with separate *ES* records for each applicable hydrologic condition.

All possible hydrologic conditions for a particular *IF* record water right are defined by a single hydrologic conditions *HC* record. The hydrologic condition is updated at intervals defined on the *HC* record of any number of months ranging from one to 12 months. The *HC* record is referenced by multiple *ES* and/or *PF* records. Hydrologic conditions can be defined based on either of the following *HC* record HCV variables falling within specified ranges.

- Regulated monthly flow volume over a specified number of months preceding the beginning of a specified season at one or multiple control points. Alternative options allow the hydrologic condition variable to be regulated flow either including (HCV=RF) or omitting (HCV=RR) releases from reservoirs located upstream.
- Naturalized monthly flow volume over a specified number of months preceding the beginning of a specified season at one or multiple control points (HCV=NF).
- Beginning-of-season storage content volume of one or multiple reservoirs (HCV=ST).
- Hydrologic conditions for each month are determined external to the simulation and provided as input on hydrologic index *HI* records (HCV=HI). Indexes such as the Palmer hydrologic drought index may be adopted to define hydrologic conditions.
- The HCV may also be the target computed for another water right, typically a type 8 *WR* record right, which can reflect any combination of *SIM* target building options.

Flow Regime Components

All of the SB3 environmental flow standards established to date include subsistence flow, base flow, and high pulse flow components. However, the *SIM* and *SIMD* simulation models view all of these components as being optional. The subsistence, base, and high flow (*ES* record) and high pulse flow (*PF* record) components are employed or omitted as controlled by the parameters on the input records. The high flow component option on the *ES* record is normally not used in a *SIMD* daily simulation since daily high pulse flow *PF* and *PO* records are available. However, *PF* and *PO* records are not applicable in a monthly *SIM* simulation.

One of the following *ESV* variable options is selected with input parameter *ESV* in *HC* record field 3 for purposes of differentiating between subsistence, base, and high flow components of flow regimes. Regulated flow is the default *ESV* normally employed.

- 1 The default *ESV* option 1 is the regulated flow in the current time step at the control point of the *IF* record at the priority of the right in the water right priority sequence.
- 1 With an entry of -1 for *ESV*, the *ESV* variable is regulated flow without releases from upstream reservoirs.
- 2 Naturalized flow at the water right control point in the current time period is used as the *ESV* variable for differentiating between subsistence and base flows.
- 3 *ESV*=3 activates the option of adopting the hydrologic condition variable (HCV) as the *ESV* variable, but without the summation over multiple preceding months.
- 4 The *ESV*=4 option consists of adopting the hydrologic condition variable (*ESV*=HCV) including the summation over multiple preceding months. For example, if the HCV is the regulated flow volume over the preceding 12 months, the *ESV* would also be the regulated flow volume over the preceding 12 months.

Each *ES* record represents a flow regime option (*ESF* = SUBS, SF50, BASE, HAnn, or HSnn) paired with a hydrologic condition (*ESHC* = 0, 1, 2, 3, ..., 9). *ESHC*=0 means the *ES* record is applicable regardless of hydrologic condition. Each of the five possible flow regime components can be connected to one of up to a maximum of nine possible hydrologic conditions. Each *ES* record reflects a different pairing of *ESF* and *ESHC*.

One of five ESF options are assigned to each *ES* record by the four-character entry in *ES* record field 2. The *ES* record ESF options are as follows.

- SUBS – Subsistence flow with regular (non-50% rule) rules for application.
- SF50 – Subsistence flow applied with the 50% rule defined below.
- BASE – Base flow.
- HAnn – High flow with a maximum limit of nn adoptions per year. The *ES* record ESQ(wr,es.m) are applied no more than nn months or days during each year.
- HSnn – High flow with a maximum limit of nn adoptions per year. The *ES* record ESQ are applied no more than nn months or days during each season.

Hydrologic conditions are specified by a one-digit integer between 1 and 9 entered as ESHC in *ES* record field 3 immediately after ESF in field 2. Water right EFS-1 on page 115 has a subsistence flow *ES* record which is applied with hydrologic condition 1 using the 50% rule (SF501) and three base flow *ES* records applied with hydrologic conditions 1, 2, and 3, respectively (BASE1, BASE2, and BASE3).

In each month of a monthly *SIM* simulation or each day of a daily *SIMD* simulation, stream flows at the control point of the *IF* record (or *WR* record) water right are classified as subsistence (SUBS or SF50), base (BASE), or high (HAnn or HSnn) flows as a function of the *HC* record *ESV* variable, and *ES* record ESQ flow limit quantities. The *IF* record instream flow target (or *WR* record target) is determined based on the flow regime classification determination.

The 50 percent rule is employed in some of the actual SB3 standards listed in Table 4.3. The 50% rule is one of the two options are provided in *SIM* for setting subsistence flow targets. With either option, the target is set at the subsistence flow limit if the *ESV* is less than or equal to the subsistence flow limit. With the 50% rule option activated, if the *ESV* volume exceeds the subsistence flow limit but is less than the base flow limit, the instream flow target is set equal to the subsistence flow limit plus 50 percent of the difference between the *ESV* volume and the subsistence flow limit. Alternatively with the standard (non-50% rule) option, if the *ESV* is less than the base flow limit, the instream flow target is set equal to the subsistence flow limit.

The following rules are applied to set a minimum instream flow target for each month of a *SIM* or *SIMD* monthly simulation or each day of a *SIMD* daily simulation.

1. If the simulated *ESV* (regulated flow by default) is less than or equal to the subsistence flow limit ESQ for the current hydrologic condition, the target is set at the subsistence flow limit.
2. If the *ESV* exceeds the subsistence flow limit but is less than the base flow limit, the following two alternative rules are possible. The instream flow limit is set equal to the subsistence flow limit if ESF=SUBS. The 50 percent rule is applied if ESF=SF50.
3. If for the current hydrologic condition there is no subsistence limit (SUBS or SF50) in effect or the *ESV* equals or exceeds the base flow limit, the target is set at the base flow limit unless the base flow limit is over-ridden by a higher high flow (*ES* record) or pulse flow (*PF* record) limit. The *ES* record high flow limits are in effect if the *ESV* exceeds the ESQ limit and the nn count has not been exceeded that year (HAnn) or *HC* record season (HSnn).
4. Daily *PF* record high pulse flow limits may over-ride the *ES* record target in a daily *SIMD* simulation as explained in the *Daily Manual*. By default, the largest targets control.

Specifying Targets and Rules for Meeting the Targets

WRAP-SIM provides considerable flexibility for modeling complex water resources development, allocation, management, and use practices. Water use requirements, reservoir/river system operating rules, and storage and conveyance structures are modeled in association with water rights. Water rights are addressed here from the perspective of input data records and associated computations performed by the model. An actual water management scheme and associated water right permit can be modeled by a combination of any number of water right input records. The various water right modeling features can be combined in a variety of ways to represent each particular aspect of a reservoir/river/use system. Modeling water rights may be very simple or quite complex depending on the particular application.

Table 4.5 provides a categorization of the different types and features of water rights. The input records used to activate the various features are also shown. In *WRAP* terminology, a water right is a water management scheme described by the information entered on either a *WR* record or *IF* record along with auxiliary records tied to the *WR* or *IF* record. *WR* records specify requirements for water supply diversions and return flows or hydroelectric energy generation. *WR* records are also used to refill/maintain storage in reservoirs at specified capacities subject to water availability. *IF* records are used to establish instream flow targets, typically associated with environmental needs, and optionally may include releases from storage to meet flow targets.

A *WR* record right, with associated *WS* record, may include refilling storage in one reservoir called its *primary* reservoir. An instream flow, water supply diversion, or hydroelectric energy requirement may be met by stream flow and/or releases/withdrawals from the primary reservoir and multiple secondary reservoirs. *Secondary* means the reservoir releases to meet instream flow, diversion or hydropower targets associated with the water right, but its storage is not refilled in association with that particular right. It is refilled by one or more other rights (*WR/WS* records). Multiple rights with different priorities may refill storage to different levels in the same reservoir.

Reservoir storage parameters on *WS* records and operating rules on *OR* records may be associated with either *WR* or *IF* records. Run-of-river diversion or hydroelectric energy generation rights may be modeled by specifying zero active storage capacity. *WR/WS* records may also specify a storage-only right used solely to refill storage with zero entered for the diversion target.

Diversion, instream flow, and hydropower requirements are typically specified by entering an annual target amount along with a set of 12 monthly distribution factors. The targets may also be altered internally within the model as a user-specified function of storage or stream flow. Alternatively, multiple-year time series of targets may be provided as input. Target setting options may be combined in a variety of ways.

An instream flow target is a minimum regulated flow at a control point. Water rights junior to the *IF* record right are curtailed as necessary to maintain the target minimum flow. An instream flow requirement (*IF* record) may be specified either without or with associated reservoir storage (*WS* record). Either way, inflows to reservoirs associated with junior rights are passed through the reservoirs as necessary to maintain the instream flow target. However, releases from storage to meet instream flow requirements are made only from reservoirs associated with the *IF* record by attached *WS* records.

Table 4.5
Classification of Water Right Features

Water rights are categorized as either water right *WR* record or instream flow *IF* record rights.

- *WR* record rights include requirements for diversions and return flows, hydroelectric energy generation, and/or filling reservoir storage.
- *IF* record rights set requirements for minimum instream flows.

Water rights may include the following optional features for specifying diversion, instream flow, hydropower, and storage targets.

- * constant annual amount combined with monthly distribution factors (*WR/IF* fields 3-4, *UC*)
- * target series that vary between years as well as between months of the year (*TS* record)
- * specification of diversion and instream flow targets as a function of naturalized/regulated/unappropriated flows, reservoir storage, and/or stream flow depletions (*TO, FS, CV* records)
- * drought index that allows diversion, instream flow, and hydropower requirements to vary as a function of reservoir storage (*DI, IS, IP, IM* records; *IF* field 10; *WR* field 11)
- * hydrologic index series on *HI* records in HIS file accessed by *TO, FS, and CV* records.

Water rights may also include the following optional features for specifying system operating rules.

- * secondary backup right that supplies shortages incurred by other rights (*BU* record)
- * stream flow depletions from alternate locations (*SO* record field 5)
- * annual or seasonal limits on diversions (*SO* record fields 10, 11, 12)
- * limits on stream flow depletions (*SO* fields 3-4 and 11-12; *ML* record; *LO* record)
- * monthly/seasonal/annual limits on withdrawals from reservoir storage (*SO* fields 7-8, 11-12)
- * monthly varying reservoir storage capacity (*MS* record)
- * multiple entities sharing storage capacity in the same reservoir (*EA* record)
- * multiple reservoir system operations (*WS* and *OR* records)
- * hydroelectric power operations (*HP* record)
- * water management schemes that circumvent the priority system (*PX* record)

WR record water rights are categorized as either Type 1, 2, 3, 4, 5, 6, 7, or 8 in *WR* record field 6.

Type 1: default standard right may include diversion and return flow, refilling storage in one reservoir, and releases from any number of reservoirs. Diversion requirements are met from reservoir storage if and only if sufficient stream flow is not available.

Type 2: same as type 1 except that refilling of reservoir storage is not allowed

Type 3: same as type 2 except diversions can be supplied only from reservoir storage

Type 4: flow is discharged into the stream

Type 5: hydropower right, same as type 1 except a hydroelectric energy generation requirement is specified instead of a diversion requirement

Type 6: hydropower right with stream flow depletions not allowed, meaning electric energy is generated only from releases from reservoir storage and the reservoir is not refilled

Type 7: reservoir storage refilling target is determined and applied

Type 8: target is computed solely for use with other water rights

In addition to the features listed in Table 4.5, a watershed flow option for distributing naturalized flows may be activated by the *SO* record. The watershed flow option is described in Chapter 3 along with the other flow distribution methods. It is different than the other methods in regard to being associated with a water right (*WR* record) rather than a control point (*CP* record).

Water management and use requirements are based on meeting:

- reservoir storage demands/needs/targets
- water supply diversion demands/needs/targets
- hydroelectric energy production demands/needs/targets
- instream flow demands/needs/targets

to the extent allowed by available water subject to the water rights priority system, operating rules and practices, and the configuration and capacities of storage and conveyance facilities. The terms *targets*, *demands*, *needs*, and *requirements* are used interchangeably in this report.

The organization of the *SIM* simulation algorithms is outlined by Figure 2.2 and the accompanying discussion in Chapter 2. In a given month, in considering each individual right in priority order in the water rights computation loop, the following tasks are performed by the model for each right in turn.

Task 1: The diversion, hydropower, storage, or instream flow target for the month is set.

Task 2: The amount of stream flow available to a *WR* record right is determined.

Task 3: Water allocation algorithms determine stream flow depletions, reservoir releases and storage changes, net evaporation-precipitation volumes, and the portion of the diversion and hydropower targets that are met and associated shortages.

Task 4: Unappropriated and regulated stream flows are adjusted for the effects of the right.

The next section outlines the system for setting water management/use targets (Task 1). Features for modeling multiple-owner and multiple-reservoir operating rules for meeting the targets (Tasks 2 & 3) are then described. The chapter then covers the dual simulation option and options for modeling water management schemes that circumvent the priority sequence. Other special optional modeling capabilities are also presented in the remainder of the chapter.

Setting Diversion, Instream Flow, and Hydropower Targets

In many typical modeling applications, targets are defined by simply entering an annual target amount on a *WR* or *IF* record and a set of 12 monthly distribution factors on *UC* records. The targets vary seasonally but are constant from year to year. However, targets may also be entered for each individual month of the multiple-year period-of-analysis, varying from year to year as well as seasonally. Options also provide flexibility for defining targets as a function of reservoir storage, current or accumulated past river flows and/or stream flow depletions appropriated by specified rights, and other variables, as well as month of the year.

Water use requirements may be specified by a single option in *SIM*, or alternatively, requirements may be computed within the model by combining multiple optional features. For most typical water rights, targets are defined by simply entering an annual target amount on a *WR* or *IF* record and referencing a set of 12 monthly distribution factors entered on *UC* records.

However, ingenuity may be applied to combine any number of the options outlined below to model complex and/or unique water management situations.

The sequentially ordered steps described below are governed by *WR/IF/UC*, *BU*, *DI/IS/IP/IM*, *TO*, *TS*, *CV*, *FS*, and *SO* records. Embedded within the sequence of tasks, optional step 4 consists of a series of any number of target building tasks with each task being governed by a separate *TO* record. Steps 2 and 10 apply a *BU* record backup feature based on shortages from one or more other *WR* record rights. Step 9 consists of referencing a *FS* or *CV* record located in the record group of another water right with its own *WR/IF/UC*, *BU*, *DI/IS/IP/IM*, *TO*, *TS*, *CV*, *FS*, and *SO* records. These cross-connections between water rights provide considerable flexibility in setting targets but also add complexity in describing and applying modeling options.

In a given month of the simulation, as the water rights are considered in turn in priority order, *SIM* builds a monthly diversion, instream flow, or hydroelectric energy target for the current water right in sequential steps as outlined below.

1. The model combines the annual diversion, hydroelectric energy, or instream flow requirement amount entered in a *WR* or *IF* record with monthly distribution coefficients from *UC* records to obtain a target for each of the 12 months of the year. *UC* records are not required if the monthly target is constant over the year. Alternatively, an instream flow *IF* record right target can be established as specified in SB3 environmental flow standard format by *HC*, *ES*, *PF*, and *PO* records.
2. The backup option activated by the *BU* record allows a water right to serve as a supplemental backup right for one or more other rights. Shortages incurred by the other rights are added to the target of the backup right. The shortage may be added at this step or as step 10. Optional step 2 consists of adding the shortages incurred by one or more other *WR* record water rights to the target of the current right determined in step 1 above.
3. The optional drought index defined by a set of *DI/IS/IP* records modifies the target as a function of the storage content of specified reservoirs. The drought index may be applied here as step 3 or later as step 6. The location of the drought index adjustment in the computational sequence is specified with the *DINDEX* entry on the *IF* or *WR* record. Step 3 consists of multiplying the target volume determined in steps 1 and 2 above by a factor determined by the drought index as a function of reservoir storage.
4. *SIM* uses several variables entered on one or multiple *TO* records to build diversion and instream flow targets. Targets may be a function of naturalized, regulated, or unappropriated flow multiplied by a factor. The target may be set based on reservoir storage or stream flow depletions incurred by other rights, which may also be multiplied by a factor. Upper and lower bounds on the target may be applied in two different ways here in the repetitive step 4.

Several *TO* records may be used to build a target step-by-step. The first *TO* record results in a target to be combined with the intermediate target determined in the preceding steps outlined above. Each subsequent *TO* record results in another target to be combined with the preceding intermediate target. The two targets are combined in each step by either (a) selecting either the maximum or minimum or (b) adding them. The target developed in this

manner may be a function of the summation of naturalized, regulated, and/or unappropriated stream flow at multiple control point locations, stream flows at various locations, reservoir storage, stream flow depletions by other water rights, and/or user specified lower and upper bounds. Flexibility is provided for combining these features as needed.

5. A time series of monthly diversion, hydroelectric energy, or instream flow targets for each month of the hydrologic period-of-analysis may be entered on *TS* records. The *TS* record may be the only option used for a particular water right, or *TS* record targets may be combined with the other options. Either (a) the greater or lesser or (b) the summation or product of the steps 1–4 versus step 5 values for a particular month is adopted depending on the value for *TSL* entered in the second field of the *TS* record for the first year.
6. A drought index defined by a set of *DI/IS/IP* records modifies the target determined above as a function of the storage content of one or more specified reservoirs. The preceding intermediate target is multiplied by a factor determined from a relationship defined by *DI/IS/IP* records. The drought index may be applied at either step 3 or step 6.
7. The target is constrained by upper and lower limits from the *TO* record if TOTARGET option 10 is specified. Otherwise, these *TO* record limits are included in step 4.
8. A flow switch *FS* or cumulative volume *CV* record may modify the target based on the total volume of a selected variable accumulated during a specified preceding number of months and/or current month. With a *FS* record, one of two alternative multipliers are applied to the target depending on whether the defined variable during the current month or accumulated during the past period of any number of months fall within a specified range. A *CV* record provides several options for creating or modifying a target. Unlike step 9 below, step 8 applies the any number of *CV* and *FS* records entered with the current *WR* or *IF* record water right along with the other records.
9. The *FS* or *CV* record for step 9 is entered with another water right and referenced by an integer identifier in *WR* field 10 or *IF* field 9 of the current right. A negative *FS* record reference results in the target of the current right being multiplied by a flow switch consisting of a factor selected by the referenced *FS* record. Otherwise, the referenced *FS* or *CV* record provides a target volume for the current right. The target volume or switch multiplier factor provided for the current right by the *FS* or *CV* record may reflect the preceding steps 1-8 for the water right record group in which the *FS* or *CV* record is located. Water right type 8 allows a right to be used solely for this type of *FS/ CV* record application.
10. The backup option activated by the *BU* record may be applied as either step 2 or step 10. The backup right's own target is first determined as outlined above, and then shortages incurred by one or more specified other rights are added.
11. The target is adjusted as necessary to prevent exceeding the optional monthly or annual reservoir withdrawal limits entered in *SO* record fields 7 and 8.
12. The target is adjusted for the annual or seasonal diversion or regulated flow limits of *SO* record field 10.

SIM applies steps 1 through 10 in sequential order to set the diversion, instream flow, or hydropower target for a water right. Steps 11 and 12 refer to additional adjustments to the target governed by *SO* record parameters that limit the amount of water available to the right. Water availability for a right may be limited by monthly or cumulative seasonal or annual limits on stream flow depletions and the amount of water that may be withdrawn from reservoir storage. An annual or seasonal diversion limit may also be placed on the total water diverted by a right.

Intermediate targets may be computed in the 12-step process outlined above of setting the actual target to be used in the simulation. Only one of these targets and associated shortage are written to the *SIM* output file. *ISHT(wr)* in *SO* record field 9 specifies which target and corresponding shortage to write to the output file. The default (blank field 9) is to write the final target and shortage at the end of the computations to the output file. Entering a 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 in *SO* record field 9 results in recording the monthly target at the completion of the specified step. If the steps 2 through 12 options are not applied, the same step 1 target and shortage are written to the output file regardless of the *ISHT(wr)* entry.

The final target is always used in the simulation computations. *ISHT(wr)* in *SO* field 9 governs the choice of which monthly targets and shortages are written to the *SIM* output file. The simulation computations are not affected in any way except for the back-up feature activated by a *BU* record or *SO* record field 6. The shortage of the other rights added to the target of the back-up right is the shortage specified by *ISHT(wr)*.

Diversion and Instream Flow Targets as a Function of Stream Flow, Storage, and Other Rights

The target options *TO* record provides options implemented as step 4 of the sequential 12-step process described in the preceding section for computing monthly diversion or instream flow targets as functions of (a) naturalized, regulated, or unappropriated flow, (b) reservoir storage or storage drawdown, (c) water taken from stream flow or reservoir storage by other rights, and (d) user-specified upper and lower bounds. Storage drawdown is capacity less storage content. The targets may be functions of stream flows or storage optionally in either the previous month or current month. If the current month option is adopted, unappropriated stream flow is the flow that is still unappropriated at the step in the water rights priority loop computations at which the right is considered. Likewise, with the current month option, the regulated flow and end-of-period storage reflect only the effects of senior rights.

The following simple example illustrates the general approach of applying *TO* records. Example 5 in Appendix C provides further illustration.

Example: Subject to water availability, regulated flows at control point CP1 are maintained to not fall below the minimum level defined by the following instream flow target. The target is set as a function of naturalized flows at CP1 and the summation of available flows at CP2 and CP3. Available flows are the unappropriated stream flows considering all water rights that are senior to this right. For each month, the target is set at 25 percent of the total sum of the unappropriated flows at CP2 and CP3, except the target can not exceed the naturalized flow at CP1. Another feature of the instream flow requirement is that the target must fall within the range of 100 to 500 acre-feet/month, regardless of the flows at CP1, CP2, and CP3. This target is specified by the following *IF* and *TO* records.


```

**
**
** | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
**
IF  CP1                1985
TO   3    0.25                CP2
TO   3    .25    ADD                CP3
TO   1    CP1    MIN    100.    500.
**

```

Although each *TO* record results in a cumulative intermediate target, only the final target is used in the simulation computations. For purposes of illustration, assume that in a particular month of the simulation, the naturalized flow at CP1 is 635 ac-ft and *WRAP-SIM* computes available flows of 800 and 400 ac-ft at CP2 and CP3. The target is set by *WRAP-SIM* step-by-step as follows.

```

IF  CP1                1985
TO   3    0.25                CP2

```

The first intermediate target is computed as: $(0.25)(800) = 200$ ac-ft

```

TO   3    .25    ADD                CP3

```

The target is computed as: $200 + (0.25)(400) = 300$ ac-ft

```

TO   1    CP1    MIN    100.    500.

```

The target is the minimum of 300 or $(1.0)(635)=635$ which is 300 ac-ft.

The target is the maximum of 300 or the lower limit 100 which is 300 ac-ft

The target is the minimum of 300 or upper limit of 500 which is 300 ac-ft.

Thus, in the example, *SIM* determines a minimum instream flow target of 300 ac-ft for that month. This target was built step-by-step by combining several options.

Flexibility is provided by *TO* record options to creatively combine target-building features in a variety of ways to model a broad range of water management situations. Targets can be computed by *SIM* by adding and/or subtracting flows at any number of locations; combining other types of flows at other locations; adopting the minimum or maximum of these values; and placing upper and lower bounds on the flows. Stream flow falling within different bounds may be multiplied by different factors. A reservoir may be refilled with a diversion with the target determined based on the reservoir drawdown limited by regulated flows. Targets may depend upon the amount of water taken by other water rights.

Diversion, Hydropower, and Instream Flow Target Series Entered on TS Records

The purpose of the target series *TS* record option is to provide flexibility for diversion, instream flow, or hydropower targets to be developed outside of the model and entered as input. The targets entered on *TS* records may be determined by various means independently of *SIM* or perhaps from the results of previous *SIM* simulations. The *TS* record targets may be the only

requirements specified for a particular water right or alternatively may be integrated with other target-building options. Targets from *TS* records are integrated into the sequential step-by-step *SIM* target building scheme as step 5 of the previously outlined 12-step process. *TS* records may be used to modify targets computed within the model with other options. Targets may be arithmetically manipulated by adding, subtracting, or multiplying numbers from *TS* records.

The target series *TS* records allow monthly diversion, instream flow, and hydropower demands to be specified that vary between years as well as seasonally. If the *TS* option is adopted, targets cover every month of the hydrologic period-of-analysis. However, the number of *TS* records may range from one to the total number of years in the simulation. The 12 monthly targets entered on a *TS* record may represent just one year or be repeated for any group of years or the entire simulation period. Example 5 in Appendix C includes *TS* records.

Drought or Storage Index

The various options activated by the *WR*, *IF*, *SO*, *TO*, *FS*, *CV*, *TS*, and *DI/IP/IS/IM* records may be combined in a myriad of ways to define diversion, instream flow, and hydropower targets. Drought indices defined by sets of *DI*, *IP*, *IS*, and *IM* records may be combined with the other records in the target building process or alternatively may be applied independently. Examples 1 and 9 in Appendix C illustrate the use of *DI*, *IP*, *IS*, and *IM* records.

The term *drought index* is adopted because depleted storage is viewed as an indicator of prolonged dry conditions with diminished water resources. The drought index option allows instream flow, diversion, and hydropower requirements to vary with reservoir storage content. The drought index option may be used as a mechanism for modeling reservoir system operations. However, more generically, a drought index can be used to allow any water use target to vary as a function of storage content, including instream flow, run-of-river diversion, and other water use requirements not met by releases from the reservoirs included in the drought index. This feature may be adopted for any application in which water use requirements are expressed as a function of reservoir storage. *JO* record field 8 is a switch allowing either beginning-of-month storage or the latest end-of-month storage computed in the water right priority loop to be used for the index.

Drought indices are assigned integer identifiers (1, 2, 3, ...) in the sequential order that the *DI/IS/IP* records for each index are entered in the input file. Entering one of these integer identifiers on an *IF* or *WR* record connects a water right to a drought index. Any number of water rights can be assigned the same drought index, and there can be any number of drought indices.

Each drought index consists of a drought index reservoirs *DI* record and drought index storage *IS* versus percentage *IP* records. The *DI* record specifies the selection of reservoirs upon which to base the index. Either all of the reservoirs in the model or a selection of up to 12 reservoirs may be specified. The *IS* and *IP* records provide a table of reservoir storage versus percentage. The reservoir storage values on the *IS* record refer to the total storage content of the reservoirs specified by the *DI* record. The corresponding percentage on the *IP* record are factors by which the instream flow, diversion, and/or hydroelectric energy requirements are multiplied.

Drought indices are incorporated in the *SIM* simulation computations as follows.

1. A parameter entered in *JO* record field 12 allows either beginning-of-month storage or the latest end-of-month storage computed in the water right priority loop to be used for the index. Either at the beginning of the month or at the pertinent point in the priority sequence, the storage contents of the specified reservoirs are summed to obtain a total storage for the drought index. All of the reservoirs in the model or up to 12 reservoirs can be selected for each drought index.
2. Linear interpolation is applied in combining the total storage associated with a particular drought index with the storage versus percentage relationship from the *IS/IP* records to obtain a multiplier factor expressed as a percentage.
3. The percentage converted to a fraction is multiplied by the permitted instream flow, diversion, and/or hydroelectric energy targets for each right assigned to a particular drought index.
4. After adjusting the target instream flow, diversion, and hydropower amounts in the previous step, all computations proceed normally without any other change related to the drought index.

An *IM* record consists of switch variable entries for each of the 12 months of the year. A *DI/IS/IP* record index can be applied with or without adding an *IM* record. An *IM* record allows the *DI/IS/IP* storage index to be switched on or off in each month, meaning the *DI/IS/IP* record storage index is applied only in specified months of the year. Alternatively, using the *IM* record, the index determined based on reservoir storage contents in a selected month may be repeated in later months. For example, the index applied in setting a target during each month of October through February could be determined based on the storage content at the beginning of October.

The inclusion of certain reservoirs in the drought index assigned to particular water rights does not otherwise associate the reservoirs with the water rights. *WS* and *OR* records are connected to *WR* and *IF* records identically the same with or without assigning a drought index to the *WR* record. Instream flow, diversion, and hydropower generation requirements associated with a water right may be determined as a function of a particular drought index without the *DI* record reservoirs making releases for these requirements or being otherwise associated with the right.

The switching-variable *EMPTY* of the *DI* record allows reservoirs to be emptied either every month or annually on a specified month of the year. In the model, the water from the reservoir is loss from the system. This *DI* record emptying feature was added to *SIM* prior to the addition of the *FS* and *CV* record features described in the next section and is now essentially superseded by the newer *FS* and *CV* records. The *EMPTY* feature is designed to be used to specify targets as a function of cumulative flows or diversions. For example, freshwater inflows into a bay and estuarine system may be expressed as a function of cumulative inflows to date that year. A *computational* reservoir with zero evaporation may be placed at the basin outlet to model the accumulation of inflows into a bay or estuary. The zero-evaporation, zero-inflow *computational* reservoir could be assigned a control point not connected to the system to model a sink or accumulation of diversions that are transported to the *computational* reservoir as return flows.

Example Drought Indices

The following two drought indices are designed for insertion at the end of the DAT file of the example in the *Fundamentals Manual*. Any number of *WR* and/or *IF* records may reference these *DI* record drought indices defined based on storage in the six reservoirs.

DI	1		3	Belton	George	Grang						
IS	4		0.0	224080.	224080.	1466320						
IP			0.0	0.0	100.0	100.0						
IM	1	2	3	4	5	-5	-5	-5	-5	-5	11	12
**												
DI	2		3	PK	Whit	WacoL						
IS	4		0.0	555776.	555776.	3391940						
IP			0.0	0.0	100.0	100.0						

Drought conditions for water rights connected to the two drought indices are defined as the storage contents of the reservoirs falling below 40 percent of their conservation storage capacity. Drought index 1 is based on the total storage contents of three reservoirs with identifiers Belton, George, and Grang and a total storage capacity of 1,466,320 acre-feet including conservation and flood control pools. The 224,080 acre-feet on the *DI* record represents 40 percent of their total conservation storage capacity. The drought index is 0.0%, representing a target multiplier factor of 0.0, if the total storage in the three reservoirs is at or below 224,080 acre-feet and 100%, representing a target multiplier factor of 1.0, if the storage exceeds 224,080 acre-feet. Likewise, drought index 2 is defined similarly by the second set of *DI*, *IS*, and *IP* records similarly based on three other reservoirs (PK, Whit, and WacoL) located in a different sub-basin.

Drought index 1 is set at the beginning of January, February, March, April, May, November, and December and applied that month. The drought index set at the beginning of May is applied in May, June, July, August, September, and October. For drought index 2, the index is reset each month based on beginning-of-month storage that month and applied in setting targets that month.

FS and CV Record Options Based on Cumulative Volumes

Flow switch *FS* and cumulative volume *CV* record options use a cumulative volume of a selected variable in developing

- *IF* record instream flow targets,
- *WR* record diversion, hydropower, or storage targets,
- *LO* record maximum stream flow depletion limits, or
- *OR* record maximum reservoir release limits.

A multiple-period past history of flows or other quantities is incorporated in setting instream flow, diversion, and hydropower targets. *FS* and *CV* records can also be used with type 7 rights (*WR* field 6) and reservoir release capacities (*OR* fields 9, 10, 11) in defining reservoir operating rules or with *LO* records for setting maximum limits on stream flow depletions. Any number of *FS* and *CV* records can be provided for any of the water rights in a *SIM* input dataset. Any number of water rights can apply the same *FS* or *CV* record. Examples 8, 9A, and 9B in Appendix C of this manual focus on *FS* records.

One of the following *FSV* or *CVV* variables is selected in *FS* or *CV* record field 3.

1. regulated flow at a control point either including or excluding reservoir releases
2. naturalized flow at a specified control point
3. unappropriated or available flow at a specified control point

4. stream flow depletion at a specified control point
5. diversion at a specified control point
6. inflow to a control point excluding upstream releases
7. stream flow depletion for a specified water right
8. total diversion for a specified water right
9. diversion from reservoir storage for a specified water right
10. target for a specified water right
11. instream flow shortage for an *IF* record right
12. hydrologic index series provided on *HI* records in a HIS file

The cumulative volume of the selected variable is computed by *SIM* by summing over the current and/or specified number of preceding time intervals. The preceding time period over which the selected variable is accumulated (summed) is defined by specifying the number of intervals and relevant season of the year. The *FS* and *CV* records include parameters for specifying a length of time that may include the current month and any number of preceding months in the *SIM* simulation (or days in *SIMD*). The time period may be limited to a season of the year defined by beginning and ending months of the relevant season of an annual cycle.

During the months at the beginning of the simulation, the number of preceding months in the specified accumulation period may still exceed the number of preceding months that have been simulated. In this case, the excess months in the accumulation period are each assigned a volume equal to the average volume for the months that have been simulated.

The choices of flow switch *FSV* or cumulative volume *CVV* variable and the rules for defining the time period over which the volume for this variable is summed are identically the same with either the *FS* or *CV* record. However, the options for using the cumulative volume to develop water right targets, stream flow depletion limits, or reservoir release limits differs between the *FS* and *CV* records. *FS* and *CV* record capabilities are described as follows.

FS Record Flow Switch

The primary motivation for including the flow switch feature in WRAP is flexibility in modeling environmental instream flow requirements. However, the *FS* record options may be also applied in setting water supply diversion target, hydropower generation targets, reservoir storage targets, maximum stream flow depletion limits, and reservoir release capacities.

The computational time step is a month in *SIM* and typically a day in *SIMD*. In many applications, the *FS* record modeling feature will be more realistic in a *SIMD* daily simulation than in a monthly *SIM* simulation. However, since this manual focuses on *SIM*, the term *month* is used in the following discussion to refer to the time step. The flow switch functions in essentially the same manner in a *SIMD* simulation with a daily time step.

The flow switch *FS* record activates a feature allowing *IF* record instream flow targets, *WR* record diversion, hydropower, or storage targets, *LO* record stream flow depletion limits, or *OR* record reservoir release limits to be switched on/off or otherwise adjusted depending on whether the volume of a selected *FSV* variable in the current and/or any number of preceding

months meets a specified criterion. The *FS* record target setting rules are based on specifying two different factors which may be 1.0 or 0.0 (on-or-off switch) or any other numbers. An intermediate target or limit quantity for the current month is multiplied by one of the two alternative factors depending on conditions during any specified number of preceding months.

The flow switch defined by a *FS* record consists of the following components.

- flow switch variable *FSV*
- a criterion based on values of the specified *FSV* during the current month (day) and a specified number of preceding months (days) of the simulation
- two multiplier factors of which one or the other is applied to the water right target, stream flow depletion limit, or reservoir release limit in the current month (day) depending on whether or not the criterion is met

Any control point or water right in the *SIM* input dataset can be selected for defining a flow switch regardless of the location of the water right to which the flow switch is applied. One of the twelve variables listed on the preceding two pages is selected as the flow switch variable *FSV*. Two multiplier factors are specified on the *FS* record. The first factor is applied if the flow switch criterion is met. The second factor is applied if the criterion is not met. The two multiplier factors may be set at 1.0 and 0.0 to act as a switch which is completely on or off. However, the factors can be any numbers entered by the model-user on a *FS* record.

As an example, assume an instream flow target is activated only if the total regulated flow over the past six months at a particular control point falls within a certain range. The instream flow target for the current month of the simulation is initially set based upon the *IF* record and supporting records. If the regulated flow at the specified control during the past six months falls within the specified range, the target is multiplied by a factor of 1.0. Otherwise, the target is multiplied by a factor of 0.0.

A *FS* record flow switch is applied as step 8 or step 9 of the 12-step target building process outlined on pages 121-122. A flow switch is expressed as follows.

$$X2 = X1 \times FSV(FS,1) \quad \text{if the criterion is satisfied}$$

$$X2 = X1 \times FSV(FS,2) \quad \text{if the criterion is not satisfied}$$

where:

FSV(FS,1) and *FSV(FS,2)* are factors from *FS* record fields 5 and 6.

X1 is the intermediate value of an *IF* record instream flow target, *WR* record diversion, hydropower, or storage target, *LO* record stream flow depletion limit, or *OR* record reservoir release limit that has been computed prior to applying the *FS* record flow switch based on specifications from *WR*, *IF*, *UC*, *DI/IS/IP/IM*, *BU*, *SO*, *TO*, *TS*, *CV*, and/or other *FS* records.

X2 is the next intermediate value or final value of the target or limit quantity being determined for that time period (month or day).

Alternative Criteria for Defining a Flow Switch

The criterion for applying a flow switch is selected by the entry for the parameter $FSI(FS,2)$ in FS record field 9. The $FSI(FS,2)$ options are as follows.

- 0 – The default is to not apply the flow switch to make water management decisions in the simulation. The FSV is accumulated and counts performed solely for purposes of providing information. Program *TABLES* 2FSV and 2FSC routines can be applied to organize the results if the FS record is used with an instream flow IF record right.
- 1 – The flow switch is based on whether the cumulative total volume of the flow switch variable FSV falls within the range defined by specified lower and upper bounds.
- 2 – The flow switch is based on counting the number of times that the monthly volume of the FSV falls within the range defined by specified lower and upper bounds.
- 3 – The flow switch is based on comparing the current or most recent monthly volume of the flow switch variable FSV with the preceding cumulative total volume as a measure of increases or decreases in the FSV .

With the default blank FS record field 9 ($FSI(FS,2)=0$), the cumulative FSV volumes used with options 1 and 2 are computed and the counts used with option 2 are made even though the flow switch is not actually applied. For an IF record right, these data are recorded in the *SIM* output file and read by the 2FSV and 2FSC record routines in *TABLES*. These data can also be recorded in the message file with either a WS or FS record water right. Thus, the extent to which the criterion is satisfied can be assessed without actually applying the FS record flow switch.

With $FSI(FS,2)$ options 0, 1, and 2, a range of FSV volume is defined by specifying upper and lower bounds $FSX(FS,3)$ and $FSX(FS,4)$ in FS record fields 7 and 8.

$$\text{lower } FSV \text{ volume bound} \leq FSV \text{ volume} \leq \text{upper } FSV \text{ volume bound}$$

The FSV volume and bounds are cumulative volumes summed over the specified number of months for option 1, single-month monthly volumes for option 2, and both for option 0.

The option 1 criterion is whether the total cumulated FSV volume during the specified current and/or specified preceding months falls within the range defined by these lower and upper bounds. In each month of the simulation, the cumulated FSV volume over the specified period of time either does or does not fall within the specified range. The initial or intermediate target or limit quantity is multiplied by $FSX(FS,1)$ from FS field 5 if the criterion is met. Otherwise, the multiplier factor $FSX(FS,1)$ from FS record field 6 is applied.

With $FSI(FS,2)$ option 2 for defining a switch criterion, the FSV volume is defined as the flow volume in an individual month. In each month of the specified period, the flow volume either does or does not fall within the specified volume range. The number of months during which the flow is within the range is counted. This count is applied with the following criteria defined by upper and lower count bounds specified in FS record fields 10 and 11.

$$\text{lower count bound} \leq \text{count} \leq \text{upper count bound}$$

Count is the number of months during which the *FSV* flow volume falls within the volume bounds. The specified lower and upper count bounds have units of time steps (months or days). The flow switch criterion is whether count falls within the specified bounds. Either multiplier factor $FSX(FS,1)$ or $FSX(FS,2)$ depending on whether the count falls within the bounds.

With $FSI(FS,2)$ option 3, the flow switch criterion is based on whether and how much the *FSV* variable is increasing or decreasing. The flow switch continues to be defined as

$$X2 = X1 \times FSV(FS,1) \text{ if the criterion is satisfied}$$

$$X2 = X1 \times FSV(FS,2) \text{ if the criterion is not satisfied}$$

However, with option 3, the $FSX(FS,3)$ and $FSX(FS,4)$ entered in *FS* record fields 7 and 8 are applied by *SIM* as multiplier factors rather than bounds. $FSX(FS,3)$ and $FSX(FS,4)$ both default to 1.0. The option 3 criterion is as follows.

$$Y2 \times FSX(FS,3) \leq Y1 \times FSX(FS,4)$$

$Y1$ is the cumulative volume of the *FSV* variable summed over the specified preceding months. $Y1$ does not include the current month. $Y2$ is the volume of the *FSV* variable in the current month. Thus, with option 3 activated:

$$FSX(FS,1) \text{ is adopted if: } Y2 \times FSX(FS,3) \leq Y1 \times FSX(FS,4)$$

$$FSX(FS,2) \text{ is adopted if: } Y2 \times FSX(FS,3) > Y1 \times FSX(FS,4)$$

With defaults of 1.0 for $FSX(FS,3)$ and $FSX(FS,4)$ and the number of preceding months $FSI(FS,5)$ set at one, the criterion is whether or not the *FSV* is increasing.

Recording FS Record Flow Switch Simulation Results

Targets and target shortages are recorded in output files as described in Chapter 5 along with the other simulation results. Additional data created by *FS* records can also be recorded in the *SIM* or *SIMD* output files. For the first or only *FS* record connected to an *IF* record, two variables are recorded for each month of the simulation in the last two fields of the instream flow output record in the *SIM* OUT, SOU, and DSS output files described in Chapters 5 and 6. These two variables are tabulated with *TABLES* using the 2FSV and 2FSC time series records.

- The first variable is the total cumulative volume of the flow switch variable *FSV* during the specified sequence of time periods.
- The second variable is the count of the number of months of the specified time sequence during which the *FSV* monthly volume fell within the defined range.

Thus, the extent to which the $FSI(FS,2)$ options 1 and 2 criterion are satisfied during the simulation can be assessed without the *FS* record flow switch actually affecting water management decisions in the simulation. The *SIM* *FS* record can be combined with *TABLES* 2FSV and 2FSC records to tabulate accumulated flow volumes and monthly volume counts without basing operating decisions in the *SIM* model on the criteria. *FS* records may be attached to *IF* records that have a target of zero and thus no effect on water management/use decisions. The flows are accumulated and counted without affecting the simulation. The volumes and counts can be tabulated with *TABLES*.

The flow switch computations for a *WR* or *IF* record target can also be explored by listing simulation results in the message file. The MSS file tabulation includes the following variables.

- year and month
- water right identifier from the *WR* or *IF* record
- integer *FS* record identifier
- lower and upper bounds on flow volume from the *FS* record
- simulated total cumulative volume of the *FSV*
- count of months that the *FSV* volume was within specified bounds
- final computed target

Cumulative Volume CV Record Options

The *CV* record is similar to the *FS* record but applies a different set of options to develop targets, depletion limits, and release limits. The variables *CVV* and *FSV* selected in *CV* and *FS* record field 3 are defined identically the same. The twelve *CVV* or *FSV* variable choices are listed on pages 127-128. The time period over which the volume of the selected variable is summed is defined in the same manner. However, the *CV* record has a different set of options for applying the cumulative volume than the *FS* record. The cumulative volume of the selected *CVV* variable can be arithmetically manipulated and combined with preceding intermediate targets. Operations may be based on whether the *CVV* volume falls within specified bounds.

Parameters entered on the *CV* record control the converting of the *CVV* variable cumulative volume quantity *CVX* to the quantity *X* representing a *IF* record instream flow target, *WR* record diversion, hydropower, or storage target, *LO* record stream flow depletion limit, or *OR* record reservoir release limit, or (in combination with other records) an intermediate component in the development thereof. The computations proceed as follows.

The first intermediate value of *X* is computed with multiplication (default = 1.0) and addition (default = 0.0) factors *FSX(1)* and *FSX(2)* entered in the *CV* record fields 5 and 6.

$$X = FSX(1) \times CVX + FSX(2)$$

Optional lower and upper bounds *FSX(3)* and *FSX(4)* entered in *CV* record fields 7 and 8 are applied as specified by the parameter *FSI(2)* in *CV* record field 9. The default *FSI(2)* option 1 is to not apply the limits at all. *FSI(2)* option 2 consists of applying the bounds as follows.

- If [*X* < *FSX(3)*] then *X* is changed to *FSX(3)*
- If [*X* > *FSX(4)*] then *X* is changed to *FSX(4)*

Alternatively, with *FSI(2)* option 3, *SIM* applies the lower and upper bounds *FSX(3)* and *FSX(4)* as follows in developing the target, depletion limit, or release limit *X*.

- If [*X* < *FSX(3)*] then *X* is changed to zero
- If [*X* > *FSX(4)*] then *X* is changed to zero

FSI(2) option 4 in *CV* record field 9 is based on V_{T-1} and V_{T-2} which are the values of the *CVV* variable one day and two days before the current day of the simulation. Limits *FSX(3)* and *FSX(4)* from the *CV* record are defined in terms of ratio *R* which is a measure of the rate that the

CVV variable changed between the preceding two days. For example, for a target *X* being set for Friday, *R* of 1.25 represents a 25% flow increase between Wednesday and Thursday.

$$R = \frac{V_{T-1}}{V_{T-2}}$$

If [*R* < *FSX*(3)] then *X* is changed to zero

If [*R* > *FSX*(4)] then *X* is changed to zero

An *IF* or *WR* record target or *LO* or *OR* record limit may be developed prior to the *CV* record by *IF*, *WR*, *UC*, *TO*, *TS*, *FS*, *DI/IS/IP*, *BU*, *WS*, *OR*, and/or other *CV* records. An option for combining this preceding target or limit (*X*) with the *X* computed with this *CV* record is selected in *CV* record field 10. The options are as follows.

- Option 1 – The *X* computed by the *CV* record is its final product, with no use of a preceding target.
- Option 2 – The *X* computed by the *CV* record is added to the preceding target.
- Option 3 – The smallest of either *X* or the preceding target is adopted.
- Option 4 – The greatest of either *X* or the preceding target is adopted.
- Option 5 – The preceding target is adopted if *X* falls with specified bounds. Otherwise, *X* is adopted.
- Option 6 – The preceding target is adopted if *X* falls with specified bounds. Otherwise, zero is adopted.

In a given month of the *SIM* simulation, the final product resulting from the *CV* record operations is a monthly volume, in units such as acre-feet/month, that represents either an *IF* record instream flow target, *WR* record diversion, hydropower, or storage target, *LO* record stream flow depletion limit, or *OR* record reservoir release limit. *SIMD* allows daily or other sub-monthly time step quantities. The quantity produced by the *CV* record may be the actual target or limit adopted for that month of the simulation or an intermediate amount subject to further adjustment by *WR*, *IF*, *SO*, *TO*, *FS*, *CV*, *TS*, and *DI/IP/IS/IM* record routines.

An option activated by *FSI*(*FS*,9) in *FS* field 16 lists the following quantities in the message *MSS* file summarizing the *CV* record computations for a *WR* or *IF* record target.

- year and month
- WR* or *IF* record water right identifier
- integer *CV* record identifier
- preceding target
- CVV* variable total cumulative volume *CVX*
- final computed target

FS and CV Record Operations in the Priority Sequence

Inclusion of the current month in the summation of a selected flow switch variable *FSV* or cumulative volume variable *CVV* is complicated by the fact that *FSV* and *CVV* quantities change during the priority sequence simulation computations. One of the 12 variables listed on

pages 127-128 is selected in *FS* or *CV* record field 3 as the *FSV* and *CVV*. The first six variables refer to a control point. The last five choices are connected to a water right. For *FSV/CVV* options 7, 8, 9, 10, and 11, for which the variable to be accumulated refers to a water right, the volume in the current month is included in the summation only if the referenced water right is senior to *FS* or *CV* record water right. For options 1-6 which refer to a control point, the latest preceding value computed in the priority sequence simulation is adopted for the current month.

FSI(FS,8) specifies whether the current month is included or excluded in the *FSV/CVV* summation. *FSI(FS,8)* option 3 consists of excluding the current month. *FSI(FS,8)* options 1 and 2 include the current month. Options 1 versus 2 are slightly different if regulated flow is the *FSV* or *CVV* but are identically the same for any other choice of variable. With regulated flow selected for the *FSV* or *CVV*, option 1 differs from option 2 only if the second pass option is activated by *PASS2* in *JO* record field 14 or *IFM(IF,3)* in *IF* record field 8. With the default *FSI(FS,8)* option 1, during the second pass, the regulated flow computed during the first pass is used. With *FSI(FS,8)* option 2, the latest regulated flow computed in the second pass is used in the same manner that the latest value computed for any other *FSV/CVV* variable would be used.

Connecting *FS* and *CV* Records with *WR*, *IF*, *OR*, and *LO* Records

Any number of *FS* and *CV* records can be provided for any of the water rights in a *SIM* input DAT file. Any number of water rights can apply the same *FS* or *CV* record.

SIM automatically numbers *FS* and *CV* records in the sequential order (1, 2, 3, ...) in which they are found in the input file. The sequential numbering provides integer identifiers for the records. Model users can also enter the identifiers in *CV/FS* record field 2 to allow convenient identification of different *CV* and *FS* records when users read the input file. All *CV* and *FS* records are included together in the same sequential numbering with no differentiation between *CV* versus *FS* records. *WR* record field 10, *IF* record field 9, and *OR* record field 10 reference these integer identifiers.

FS and *CV* records can be employed in the following alternative modes.

- Any number of *FS* and *CV* records can be included in the set of auxiliary records (*SO*, *TO*, *LO*, *TS*, *BU*, *PX*, and *WS/HP/OR*) belonging to a *WR* or *IF* record. These *FS* and *CV* records are applied as step 8 of the 12-step target building process outlined on pages 121-122 to develop the water right target. The sequential *FS* and *CV* record integer identifiers have no relevance in this mode of application. Quantities are computed in the priority sequence simulation in the priority specified on the *WR* or *IF* record.
- A *WR* or *IF* record can reference a *FS* or *CV* record that is located with the records for some other *WR* or *IF* record right by entering the *CV* or *FS* integer identifier on the *WR* or *IF* record. This is step 9 of the 12-step target building process outlined on pages 121-122. The same *CV* or *FS* record results developed at the same priority can thus be applied for any number of water rights. The quantity provided by the *CV* record is a monthly target volume. Depending on *FSCV(wr)*, the *FS* record provides either a target volume or switch multiplier factor to be applied to the *WR* or *IF* record target.

Additional Water Management Options for Supplying Water Use Targets

Modeling river/reservoir/use system operations may range from very simple to very complex. Flexible options are provided to model the rules by which stream flow and reservoir storage is allocated to meet the water use targets described in the preceding sections. Table 4.5 outlines the optional water rights features for modeling various complexities or different situations. The preceding section focuses on options for setting targets modeling water supply diversion, environmental instream flow, and hydroelectric energy production targets (demands, needs, requirements). The previously discussed water right types 1-8 are fundamental in defining operating rules. The following discussion describes other options to be adopted in various combinations to model the manner in which the river/reservoir system is managed to meet these water use targets.

Backup Right

The secondary backup option allows diversion, instream flow, or hydropower shortages associated with a water right to be supplied by another right called a backup right. The backup option is activated by a *BU* record assigned to the right providing the backup. The *WR* or *IF* record right with a *BU* record serves as a backup for any number of other rights. The diversion, instream flow, or hydropower shortages computed for the one or more specified other water rights are added to the target of the backup right. The computations then proceed normally without any other change related to the backup feature. In each month, the target for the backup right is the shortage of the rights being backed up plus the target amount determined by its own *WR/IF/UC* records and target setting options on associated *SO*, *TO*, *TS*, *DI*, *FS*, and *CV* records. A backup right may also be combined with the *PX* record control point limit option discussed in the last section of this chapter.

Shortages incurred by the specified rights are added to the target of the *BU* record right within in the water rights priority loop computational sequence. If the other right is senior to the backup right, its shortage is added to the target of the backup right in the same month. If the other right is junior, its shortage is added to the backup right target in the next month.

A backup right may backup another backup right. Any number of backup rights may be placed in sequence. Each adds any shortage amount computed for the preceding backup right to its own target. Thus, a single diversion requirement can be shared by multiple rights.

Though rendered obsolete with introduction of the expanded features provided by the newer *BU* and *PX* records, *SO* record field 6 is still functional. The *SO* record field 6 option with *RETURN* entered may be used in combination with a type 4 right to assign a priority to a return flow that is different than the corresponding diversion right. A *WR* record for a type 4 right along with its *SO* record may be placed behind the *WR* and supporting records for a more senior diversion right. The diversion shortage for the first right will be applied in computing the amount *AMTRF* that the second right (type 4 right) returns to the stream as follows:

$$AMTRF_{type\ 4\ right} = T_{type\ 4\ right} - (S_{previous\ right})(RFAC_{type\ 4\ right})$$

where the target amount *T* for the type 4 right is computed as normal and then adjusted for the shortage *S* from the previous right. The more recently added transient water right *XP* option 1 activated by the *PX* record provides a simpler means to assign a different priority to return flows.

Stream Flow Depletions from Multiple Locations

Stream flow depletions to meet diversion requirements and refill reservoir storage normally occur at the control point to which the water right is assigned. This control point is specified in the second field of the *WR* record. Diversion and reservoir refilling requirements can also be met by releases from storage from one or multiple secondary reservoirs identified on *WS* records with system operating rules specified on *OR* records.

An option allows reservoir storage to be refilled from stream flow depletions at other control points. The alternate control point identifier *ACPID* entered on the *SO* record specifies the location from which flow depletions occur. Any number of *WR/SO* records, and thus alternate control point locations, can be associated with a particular reservoir. There are no restrictions on which control points to use to refill storage. The computations are based on using the alternate control point in lieu of the default control point specified in *WR* record field 2.

A typical application of this feature would be a storage reservoir located on a small tributary that is filled by pumping water from a nearby major river as well as the inflows from its own watershed. A set of *WR*, *WS*, and *SO* records allow the reservoir to be refilled from inflows from the small stream on which it is located. In months in which these inflows are insufficient to fill the reservoir to capacity, a second *WR/WS/SO* record set with an alternate control point allows the reservoir to pump water from the other stream.

Limits on Stream Flow Depletions, Diversions, and Diversions from Storage

SO record variables *MRW* and *ARW* are limits on monthly and seasonal or annual withdrawals from reservoir storage. An annual or seasonal diversion limit *ADL* may also be entered on the *SO* record. For annual limits, starting in the first month of each year, the model maintains a record of the total cumulative stream flow depletions, diversions, and the amount of the diversions that came from reservoir storage that year associated with the specified water right. Upon reaching a specified limit, no more water is available to the diversion right until the beginning of the next year. Likewise, the limit months $LM(wr,1)$ and $LM(wr,2)$ entered on the *SO* record define beginning and ending months of a season for which the limits apply.

Water right permits associated with off-channel reservoirs often limit the total cumulative amount of stream flow that may be taken each year to refill reservoir storage. Pumping and conveyance facilities as well as water rights permits may limit the amount of stream flow withdrawn each month. Options allow monthly and annual limits to be imposed on stream flow depletions associated with a water right. Without specifying this option, reservoir storage is refilled to capacity each month as long as sufficient stream flow is available to a right. The options for specifying flow depletion limits are motivated primarily by constraints on refilling off-channel reservoir storage but are applicable to major main-stream reservoirs and diversions as well. *SIM* does not explicitly differentiate between on-channel and off-channel reservoirs, and these options may be applied to either.

A stream flow depletion is the amount of water taken from stream flow by a right to meet diversion requirements, net evaporation-precipitation requirements, and refill reservoir storage. The input variable *ANNDEP* of the *SO* record is a limit on the cumulative annual flow depletion

that a right is allowed. Starting in the first month each year, the model maintains a record of the total stream flow depletions that a right has accumulated that year. Reservoir storage refilling and diversion associated with the right (*WR/WS* records) is curtailed whenever the *ANNDEP* limit is reached. The limit is treated as another constraint on water availability.

Monthly limits on the stream flow depletions associated with a water right can also be imposed. The input variable *MONDEP* of the *SO* record is a constant limit imposed each of the 12 months of the year. The amount of stream flow available to a right is constrained to not exceed *MONDEP* in any month. Alternatively, a set of 12 monthly varying limits may be specified for a right on a *ML* record.

Limits on the stream flow depletions incurred by a *WR* record water right can also be imposed with a limit options *LO* record. The *LO* record has identically the same format as the target options *TO* record. However, the *LO* record produces maximum limits on stream flow depletions rather than *TO* record diversion, instream flow, hydropower, or storage targets. The *LO* record depletion limits are computed using the same *TO* record options that are available for developing targets. The resulting *LO* record maximum stream flow depletion limit is applied in the *SIM* simulation in the same manner as the limits established by *SO* and *ML* records.

Gravity Flow in River Channels versus Pipeline/Canal/Pump Conveyance

By default, reservoir operation is based on assuming conveyance by gravity flow in river channels. Reservoir releases can meet diversion requirements at the control point of the reservoir or at any control point located downstream of the reservoir. *OR* record field 7 is used to remove the gravity flow constraint. A pipeline or canal, with pumps as needed, is assumed to convey water from the reservoir to the control point of the water right diversion, which can be any location.

Reservoir System Operations

A *WRAP-SIM* water right may include: (1) maintaining (refilling) the storage in one reservoir and (2) meeting diversion, hydropower, or instream flow requirements by diverting or releasing from storage in one or multiple reservoirs. In constructing a model, these two activities can be viewed as being essentially separate. A particular right may include either, neither, or both.

SIM input parameters defining reservoir operation rules are listed in Table 4.6 and discussed in the following paragraphs. The water right *WR*, reservoir storage *WS*, operating rules *OR*, job options *JO*, and file options *OF* records, and pairs of *SV/SA*, *PV/PE*, and *EA/EF* records noted in Table 4.6 are described in Chapter 3 of the *Users Manual* [2].

Reservoir storage parameters are provided on the storage *WS* record associated with a water right. Any number of water rights can be associated with a single reservoir. Any number of reservoirs may be associated with a single water right. A right may include a storage capacity to be refilled in only one reservoir, called its *primary* reservoir. Secondary reservoirs supply water use requirements but are not refilled by the right. Reservoir operations are defined by water right type (Tables 4.1 and 4.5) specified on *WR* records and rules specified on operating rules *OR* records along with parameters on *WS*, *HP*, and other records. Flood control operations in a daily *SIMD* simulation are controlled by *FR*, *FF*, *FV*, and *FQ* records described in the *Daily Manual*.

Table 4.6
SIM Input Parameters Controlling Reservoir System Operations

Record Field	Description of Input Parameter
WR field 6	Selection between the water right types defined in Tables 4.1 and 4.5.
WS field 3	Total reservoir storage capacity at top of conservation pool in acre-feet.
WS field 7	Reservoir storage capacity at top of inactive pool in acre-feet.
WS field 8	Storage contents at the beginning of the simulation. Default is full reservoir.
WS fields 4,5,6	Specification of storage volume versus surface area relationship.
SV/SA records	Table of storage volume in acre-feet versus surface area in acres.
WS fields 9, 10	Evaporation allocation option for multiple owner reservoir.
EA/EF records	Net evaporation-precipitation allocation for multiple-owner reservoirs.
WS field 11	Downstream releases accessible to hydropower versus lakeside withdrawals.
OR field 3	Storage capacity at top of zone 2 (bottom of zone 1). Default = inactive
OR field 4	Multiplier factor (M) in Equations 4.6 and 4.7 for zone 1. Default = 1.0
OR field 5	Multiplier factor (M) in Equations 4.6 and 4.7 for zone 2. Default = 1.0
OR field 6	Selection between rank index Equations 4.6 and 4.7. Default is Eq. 4.6.
PE/PV records	Elevation versus volume table used with rank index Equation 4.7.
JO field 11	Beginning versus end-of-period storage for multiple-reservoir release rules.
JO field 8	Options to match beginning and end of simulation storage contents.
OR field 8	Storage capacity in ac-ft at bottom of upper sub-pool. Default is no sub-pool.
OR field 9	Rank index for upper sub-pool. Default = 1.0
OR field 10	Storage capacity in acre-feet at top of lower sub-pool. Default is no sub-pool.
OR field 11	Rank index for upper sub-pool. Default = 1.0
OR field 12	Monthly reservoir release limit in acre-feet. Default is no release limit.
OR fields 13, 14	Options for using <i>CV</i> or <i>FS</i> record to compute monthly release limit.
OR field 7	Pump and pipeline versus downstream gravity flow releases from reservoir.
MS record5	Monthly storage capacity limits defining seasonal rule curve operations.
OF field 2	System operation tracking variables are recorded in the <i>SIM</i> DSS output file.
JO field 10	Hydropower and system releases in HRR file read by <i>TABLES 4HRR</i> .

Actual operations of reservoirs range from very simple to very complex. Many reservoirs can be modeled very simply without needing most of the options listed in Table 4.6. Water supply demands are supplied while maintaining the conservation pool storage level as high as possible. However, the *SIM* simulation features outlined here also facilitate modeling complex operations. Modeling is somewhat simplified by defaults being automatically activated if input is not provided.

Operation of Individual Reservoirs

Conservation storage capacity includes an active pool and inactive pool. The inactive pool capacity specified in *WS* record field 7 is dead storage from which releases or withdrawals cannot

be made by that right. In the computations associated with the *WR* record water right to which the *WS* record is connected, the inactive pool can be drawn down only by evaporation. No evaporation occurs from the inactive pool unless the active pool is empty. Different water rights associated with the same reservoir can each have a different inactive pool capacity. *WS* record field 3 specifies the total storage capacity volume at the top of conservation pool. The *MS* record allows the total conservation storage capacity to vary monthly. Specification of water right type 7 (defined in Tables 4.1 and 4.5) on the *WR* record allows the storage capacity to be computed as a target.

Releases and withdrawals to meet the requirements for a particular right are made from the active conservation pool storage above its inactive pool. A water right has access to the volume of water contained in its active conservation pool adjusted for net evaporation losses. A maximum release capacity can be specified on the *OR* record or computed by an *OR* record reference to a *FS* or *CV* record. The various quantities computed by the model for a particular water right reflect consideration of all senior rights but not junior rights. Inflows pass through a reservoir as necessary to protect more senior water rights located downstream.

Each reservoir is associated with at least one water right. Each reservoir is assigned a control point. Multiple rights and multiple reservoirs may be assigned to the same control point. Each water right has access, in priority order, to the stream flow inflows at the control point. Each right may have multiple reservoirs, one primary (refilling) and the others secondary (no refilling).

Although each reservoir may be assigned to any number of water rights, each reservoir must have one and only one storage volume versus surface area relationship entered either as *SV/SA* records or as coefficients on a *WS* record. Each reservoir associated with hydroelectric power must have one and only one storage volume versus elevation relationship entered as *PV/PE* records.

Storage capacity is specified on the *WS* record associated with a water right. Any number of water rights can be associated with a single reservoir, with each right filling the reservoir to a different storage capacity and/or using the reservoir to meet its water use requirements. *SIM* allows releases from multiple reservoirs to meet the one diversion, hydropower, or instream flow target and maintain storage in the one reservoir specified by a single water right. Options are provided for specification of multiple-reservoir/river system operating rules. Multiple reservoirs can each have one or more separate rights to maintain their individual storages. Reservoir system operations may be defined by combining any number of *WR/WS* records and other supporting records.

The cumulative total storage capacity below the top of conservation pool is specified in *WS* record field 3. A type 7 water right refills storage based on a storage target computed in the same way as a diversion target. This water right type 7 storage target is the conservation storage capacity to be filled subject to the constraint of not exceeding the capacity specified in *WS* record field 3. Seasonal rule curve operations are modeled with monthly storage *MS* records. The *MS* record option allows each reservoir to have one or none, but not more than one, set of 12 monthly storage capacity limits. The reservoir is refilled to the *WS* record field 3 storage capacity subject to the constraint of not exceeding the capacity limit for that month specified on the *MS* record.

Any number of water rights can refill storage capacity in the same reservoir and/or make releases from the reservoir to supply diversion, hydropower, or instream flow requirements. The storage capacity entered in *WS* record field 3 is the total cumulative capacity to which the reservoir

can be refilled under that right's priority, assuming the reservoir has been drawn down in previous months or by senior rights in the current month and stream flow is now available for refilling.

In performing computations for a given water right, except for hydropower rights, in a given month, the beginning-of-month and end-of-month storage is not allowed to exceed the storage capacity associated with that right. In order to appropriately determine head, hydropower rights allow the beginning- and end-of-period storage to exceed the storage capacity of the hydropower right due to other junior rights at the same reservoir.

For a reservoir with multiple rights, the storage capacity specified for each right must equal or exceed the storage capacity specified for more senior rights or else not specify refilling. Refilling occurs only with type 1 right. In the water rights priority sequence computational loop, storage capacity can remain the same or be increased but cannot be decreased as each more junior right is considered in priority order.

Flood Control Operations

SIM has no features for modeling flood control reservoir operations. In a *SIM* simulation, outflow equals inflow whenever a reservoir is full to conservation pool capacity. *SIMD* allows gated or ungated flood control pool and/or surcharge storage capacity above the top of conservation pool to be included in a daily simulation as described in the *Daily Manual*. The flood control pools in any number of reservoirs can be operated as a system in *SIMD* based on stream flows at any number of downstream control points. Releases from flood control pools of individual reservoirs can be constrained by outlet capacities. Surcharge storage can also be simulated with *SIMD*.

Multiple-Reservoir System Conservation Pool Operations

In modeling multiple-reservoir systems, rules are required for *SIM* to determine amounts to release each month from each of the reservoirs included in the system. If two or more reservoirs are associated with a water right, an operating rules *OR* record following each *WS* record defines the multiple-reservoir operating rules. An *OR* record can also be provided for a single secondary reservoir associated with a water right, if needed to either specify the control point location or maximum release capacity or to flag pipeline conveyance. The optional *OR* record includes the reservoir control point location, storage capacity at top of zone 2, zones 1 and 2 release ranking factors, specification of gravity flow versus pipeline flow, and a maximum release capacity or reference to a *FS* or *CV* record. All of the operating rule parameters entered on *OR* records have default values that are activated if the *OR* record field is blank or if there is no *OR* record. Without *OR* records, multiple-reservoir system release decisions are based on releasing each month from the reservoir that is most full in terms of percentage of active conservation storage capacity.

System operations consist of the following four components which may be employed individually or in combination. Multiple-reservoir operating rules are based on releasing in each month from the reservoir that has the largest value for the rank index in that month, which is computed in the first component described below subject to being replaced in the second component.

1. Multiple-reservoir release decisions are based on balancing storage levels by releasing from the reservoir with the largest rank index computed with either Eq. 4.6 or Eq. 4.7 using parameters entered in *OR* record fields 3, 4, 5, and 6. Equation 4.6 is based on storage

contents as a fraction of storage capacity. Alternatively, Equation 4.7 is based on reservoir drawdown in feet below the top of conservation pool. Releases are made only from zone 1 of each reservoir until zone 1 is empty in all reservoirs. When zone 1 is empty in all reservoirs, releases are made from zone 2.

2. The values of the rank indices computed with Eqs. 4.6 or 4.7 may optionally be replaced in any of the reservoirs by user-specified values of the rank indices (fields 9 and 11) whenever the simulated storage is within the upper sub-pool, defined as above the storage volume entered in field 8, or the lower sub-pool defined as below the storage volume in field 10.
3. *OR* record field 7 activates the pump and pipeline conveyance option. Otherwise, diversion sites must be located at or downstream of the dams, with conveyance only by gravity flow.
4. *OR* record fields 12, 13, and 14 allows maximum limits to be placed on reservoir releases.

Balancing Storage Contents of Zones of Multiple Reservoirs

As illustrated by Figures 4.1 and 4.2, the active conservation pool may be divided into two zones for developing multiple-reservoir operating rules. The model-user defines operating rules by *OR* record entries for cumulative storage capacities and multiplier factors for zone 1 and zone 2 for each reservoir. Zone 1 is the portion of the conservation pool above a designated elevation. Zone 2 is the remainder of the active storage capacity lying below zone 1. Zone 1 can be eliminated by specifying its cumulative capacity as equal to that for zone 2. Zone 2 may be eliminated by specifying its cumulative capacity as equal to the inactive storage capacity. With no *OR* records, the default defines the entire conservation pool as zone 1. Multiple reservoir release decisions are based on balancing the storage, as a percent of zone capacity, in each reservoir.

In each time step of the simulation, reservoir storage balancing within a particular zone is based on computing a ranking index for each reservoir in the system as follows, with the release that month being made from the reservoir with the greatest value of the index. The rank index can be computed based on either storage content volume (Equation 4.5/4.6) in acre-feet or drawdown depth (Equation 4.7) in feet, as specified in *OR* record field 6, with storage content volume being the default option. Equation 4.5 is written more concisely as Equation 4.6. The content/capacity fraction computed each month for each reservoir varies between 0.0 and 1.0.

$$\text{rank index} = (\text{multiplier factor}) \left[\frac{\text{storage content in zone}}{\text{storage capacity of zone}} \right] \quad (4.5)$$

$$\text{rank index} = M \left[\frac{\text{content}}{\text{capacity}} \right] \quad (4.6)$$

$$\text{rank index} = (-1.0) \times M \times (\text{drawdown depth}) \quad (4.7)$$

The two multiplier factors *M* for zones 1 and 2 are entered on the *OR* record, with defaults of 1.0. The input parameter STOFLG in *JO* record field 11 allows selection between two options for the storage contents to use in the rank index equations. The default is the intermediate end-of-period storage at that point in the water rights priority loop computations, which is subject to change due to more junior water rights. The alternative STOFLG option is to use the beginning-of-period storage. The storage option specified by STOFLG also applies to the drawdown in Equation 4.7.

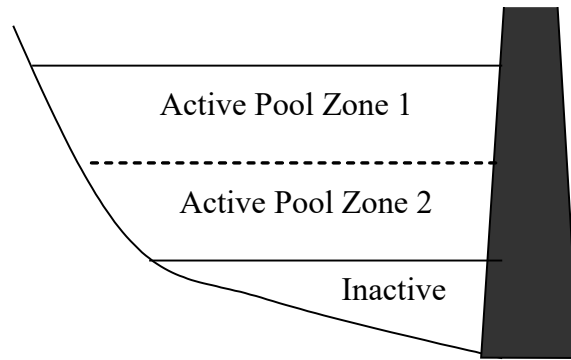


Figure 4.1 Optional Two Zone Subdivision of Active Conservation Pool

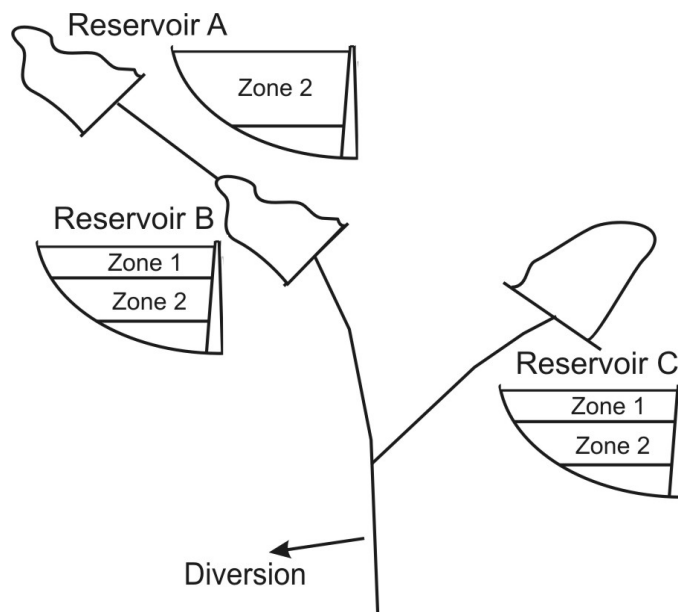


Figure 4.2 Storage Zones for Defining Multiple-Reservoir Release Rules

The drawdown depth option (Eq. 4.7) requires *PV* and *PE* records in the input DAT file for each relevant reservoir relating reservoir storage volume and water surface elevation. The same *PV/PE* record tables are used in both hydropower computations and applying Eq. 4.7 in multiple-reservoir release decisions. The water surface elevation for a given storage volume is computed by linear interpolation of the *PV/PE* record table. Depending on the *STOFLG* option selected in *JO* record field 11, the storage volume is for either the beginning of the month or the end of the month.

Drawdown depth in Eq. 4.7 is computed as the difference in feet in water surface elevation at full conservation storage capacity and the elevation at the monthly storage contents. The negative one (−1.0) in Eq. 4.7 means that the smallest drawdown has the largest rank index. The release is made from the reservoir with the largest rank index.

With defaults activated by blank fields 4, 5, and 6, a rank index between 0.0 and 1.0 is computed with Eq. 4.6 for each of the reservoirs with storage contents in zone 1 in a particular

month of the *SIM* simulation. The release for the month is made from the reservoir with the largest rank index, which results over time in approximately balancing storage contents between the multiple reservoirs.

Zone 1 must be empty in all the reservoirs in the system in order for releases to be made from zone 2 of any of the reservoirs. If only one reservoir has water in zone 1, the release will come from that reservoir. If two or more reservoirs have water in zone 1, a value for the ranking index is computed for each of the reservoirs. The release is made from the reservoir that has the largest value for the rank index. If zone 1 is empty in all reservoirs, the same selection procedure is applied based on the storage contents of zone 2 of each reservoir. If the release results in the zone 1 storage being emptied for a reservoir while other reservoirs still have water in zone 1, the release is limited to that required to empty zone 1 in that reservoir. Additional releases are made, as required, from zone 1 of one or more other reservoirs. The reservoirs are not precisely balanced since, in each month, only one selected reservoir releases for the water right, unless the release depletes the storage capacity of the zone or reaches the release limit.

The secondary reservoirs eligible to release from a storage zone for a water right are ranked according to the rank index computed with Eq. 4.6 or Eq. 4.7. If the values of the *multiplier factor* M are the same for all the reservoirs, the operating rule simply balances the percentage depletion of either zone 1 or zone 2 of each reservoir. The *OR* record weighing factors M allow some reservoirs to be emptied faster than others. If M is 0.5 and 1.0 for Reservoirs A and B, respectively, the storage content of Reservoir A, expressed as a fraction (ranging from 0.0 to 1.0) of zone capacity, must be at least twice that of Reservoir B in order for the release to be made from Reservoir A.

User-Specified Rank Indices for Upper and Lower Sub-Pools

The rank indices computed with Eq. 4.6 or Eq. 4.7 may optionally be replaced in any of the reservoirs by user-specified rank indices entered in *OR* record fields 9 and 11 during any months of the simulation during which storage contents defined by *STOFLG* in *JO* record field 11 is within the upper sub-pool, defined as above the storage volume entered in *OR* record field 8, or the lower sub-pool defined as below the storage volume in *OR* record field 10. For example, with defaults activated by blank fields 4, 5, and 6, with a rank index of any number larger than 1.0 entered in field 9 for one of the reservoirs, that reservoir will release whenever its storage contents exceeds the volume entered in *OR* record field 8.

The upper and lower sub-pools can be defined independently of the zones of Figures 4.1 and 4.2 and Equations 4.6 and 4.7. However, when combined, for example with the upper sub-pool being an upper portion of zone 1 and the lower sub-pool being a lower portion of zone 2, the two alternative strategies allow dividing the active conservation pool into up to four components. The rank index is computed with Eqs. 4.6 or 4.7 for zones 1 and 2. The rank index is specified by entries in *OR* record fields 9 and 11 for the upper and lower sub-pools. With dual rank indices in a particular month, the sub-pool rank index specified in *OR* record field 9 or 11 controls.

Example of Combining the Two Ranking Strategies

Input parameters for an example three-reservoir system are tabulated in the top of Table 4.7. Selected simulation results for two months of the simulation are shown at the bottom of Table 4.7.

Table 4.7
Example of Multiple-Reservoir System Release Decisions

Reservoir		A	B	C
<u>Parameters Entered in SIM Input DAT File</u>				
Water right type	<i>WR</i> field 6	2	2	2
Conservation capacity (acre-feet)	<i>WS</i> field 3	150,000	100,000	130,000
Inactive pool capacity (acre-feet)	<i>WS</i> field 7	25,000	0	4,200
Capacity top of zone 2 (acre-feet)	<i>OR</i> field 3	60,000	50,000	70,000
Bottom of upper sub-pool (acre-feet)	<i>OR</i> field 8	120,000	-	120,000
Rank index for upper pool	<i>OR</i> field 9	999	-	888
Bottom of lower sub-pool (acre-feet)	<i>OR</i> field 11	40,000	-	5,000
Rank index for lower pool	<i>OR</i> field 12	999	-	888
<u>Storage Volume of the Two Designated Zones and Two Designated Sub-Pools</u>				
Capacity of Zone 1 (acre-feet)		90,000	50,000	60,000
Capacity of Zone 2 (acre-feet)		35,000	50,000	65,800
Capacity of Upper Sub-Pool (acre-feet)		30,000	-0-	10,000
Capacity of Upper Sub-Pool (acre-feet)		10,000	-0-	800
<u>Computed Storage Contents and Rank Index</u>				
May 2017 Storage Contents (acre-feet)		127,854	98,567	125,943
May 2017 Eq. 4.6 Rank Index		0.7539	0.9713	0.9324
May 2017 Final Rank Index		999.0	0.9713	888.0
June 2017 Storage Contents (acre-feet)		116,753	99,021	121,435
June 2017 Eq. 4.6 Rank Index		0.6306	0.9804	0.8572
June Final Rank Index		0.6306	0.9804	888

The following additional input data are the same for all three of the reservoirs.

- STOFLG=1 is selected in *JO* record field 11 meaning the beginning-of-month storage contents is used with the rank index equation.
- Rank index Equation 4.6 is selected in *OR* record field 6.
- Defaults of 1.0 are adopted for the multiplier (M) in *OR* record field 6.

The results of the rank index computations for two months of the hydrologic period-of-analysis of the *SIM* simulation are shown in the bottom section of Table 4.7. The release for each month is made from the reservoir with the largest rank index, which is Reservoir A in May 2017 and Reservoir C in June 2017.

Equation 4.6 is applied with the May 2017 beginning-of-month storage contents of Reservoirs A, B, and C of 127,854 acre-feet, 98,567 acre-feet, and 125,943 acre-feet, respectively, to obtain rank index values of 0.7539, 0.9713, and 0.9324. The rank index for Reservoir A of 0.7539 $[(127,854-60,000)/(150,000-60,000)=0.7539]$ means the storage contents of Reservoir A is

75.39% of its zone 1 storage volume. Since the contents of Reservoir A of 127,854 acre-feet is greater than the 120,000 acre-feet limit defining the upper sub-pool, the rank index is changed from 0.5339 to 999, which is larger than the rank indices of 0.9713 and 888 for the other two reservoirs.

Application Equation 4.6 is applied with the June 2017 beginning-of-month storage contents of Reservoirs A, B, and C results in rank indices of 0.6306, 0.9804, and 0.8572. The rank index for Reservoir C is changed to 888 since the storage contents is within the upper sub-pool. The release for June 2017 is from Reservoir C.

Only the relative, not absolute, values of the rank indices are relevant. With default values of 1.0 for M , Eq. 4.6 generates rank index values ranging from 0.0 to 1.0. Other values of M can be specified to weight the rank index equation as appropriate. The relevance of the user-specified rank indices of 999 and 888 in the example (Table 4.7) are due only to their relative magnitudes. The number 999 is greater than 888 and any number between 0.0 and 1.0. Ingenuity and creativity is employed to apply the *SIM* options outlined here to model particular reservoir systems.

Other Reservoir Release Options

A maximum allowable monthly release limit for a reservoir may be specified in *OR* record fields 9, 10, and 11. A constant release limit may be specified, or alternatively the release limit can be varied with flow or other conditions using a flow switch *FS* or cumulative volume *CV* record and associated records. The limit could represent either outlet structure capacity or operating rules.

Reservoir releases meet diversion requirements at the control point of the reservoir or at control points located downstream of the reservoir by default. Downstream releases are assumed to reach the diversion site by gravity flow in the stream channel. *OR* record field 6 provides the alternative of modeling a pipeline or canal with pumps as needed to convey water from the reservoir to the control point of the water right diversion, which can be any location.

Releases for Downstream Senior Rights

Reservoirs located upstream of a diversion are assumed to make direct releases to supply the diversion requirement. The pump/pipeline/canal option activated by *OR* record field 7 allows diversions from a reservoir to be conveyed to any control point. However, without the pump/pipeline/canal option, reservoirs that are physically able to release only to control points that are downstream of the diversion location may still contribute to system operations. These reservoirs, referred to as *downstream* reservoirs, are limited to mitigating stream flow depletions made by senior rights downstream of the diversion location. The amount of water that a *downstream reservoir* may release is limited to the flow that has been passed through the diversion location to meet senior water right requirements as illustrated by the following example.

Figure 4.3 illustrates a system composed of four reservoirs and one diversion, which is subject to the constraint of another more senior water right. The system diversion can be met from stream flow depletions at control point CP-4 and releases from reservoirs RES-A, RES-B, RES-C, and RES-D located at control points CP-1, CP-2, CP-3, and CP-5. Since reservoir RES-D at control point CP-5 is not located upstream of the system diversion location at control point CP-4, its role is limited to minimizing the adverse impacts on water availability of the senior right at control point

CP-6. In each month of the simulation, the computations include determination of the amount of water to release from each subcomponent of the four-reservoir system to meet the diversion at CP-4, based on balancing storage depletions in the reservoirs.

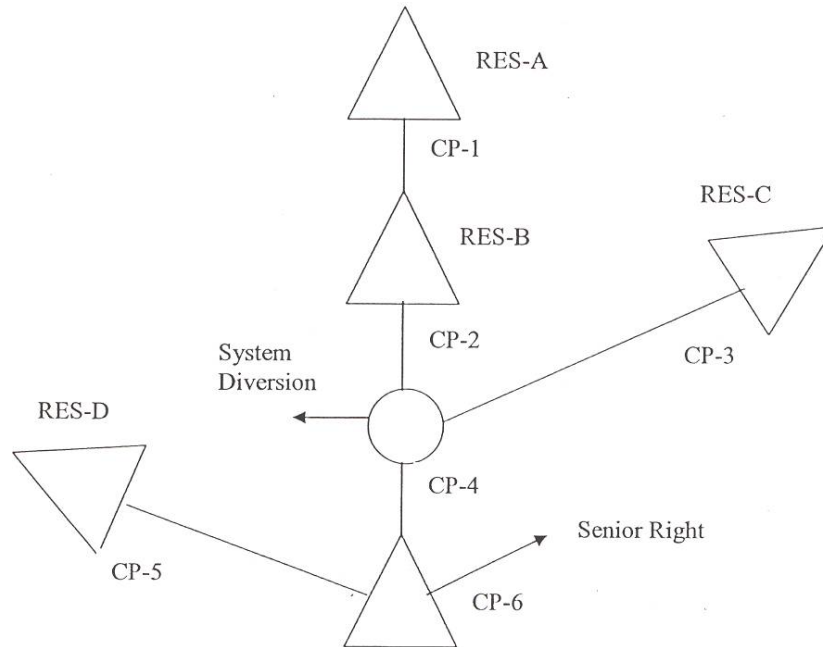


Figure 4.3 Multiple Reservoir System with a Downstream Senior Right

The multiple reservoir system release rules may involve interactions with other more senior rights in the river basin. For example, the senior right at control point CP-6 in Figure 4.3 is not part of the four-reservoir/one-diversion system but impacts the water available to the system. The model maintains an accounting of the amount by which the senior right at CP-6 reduces water availability at the other control points and allows releases to be made from reservoir RES-D, as well as RES-A, RES-B, and RES-C, to mitigate this amount. Therefore, to this limited extent, reservoir RES-D contributes to meeting the permitted system diversion at CP-4 and maintaining storage in the system reservoirs, even though RES-D is not located upstream of CP-4. Likewise, reservoir RES-A can contribute to refilling storage in RES-B and RES-C, and vice versa, in a similar manner.

In this example, water is conveyed only by gravity flow in the stream channels. However, *WRAP-SIM* includes optional capabilities for simulating pump/pipeline/canal systems. For example, water could be conveyed by pipeline from reservoir RES-D to control CP-4 to contribute to the system diversion. If appropriately flagged in *OR* record field 6, reservoir RES-D will be treated just like reservoirs RES-A, RES-B, and RES-C in making multiple-reservoir releases to meet the system diversion at CP-4, even though RES-D is not located upstream of CP-4.

Again using the system in Figure 4.3 as an example, the three upstream reservoirs RES-A, RES-B, and RES-C are able to release directly to the system diversion location at CP-4. Downstream reservoir RES-D is not. Naturalized stream flows at control points CP-4 and CP-6 are 20 ac-ft and 30 ac-ft, respectively. The senior right diversion and storage refilling requirement at CP-6 is 17 ac-ft. The system diversion requirement at CP-4 is 25 ac-ft.

The senior right stream flow depletion of 17 ac-ft reduces the available stream flow to the system diversion to 13 ac-ft, resulting in 12 ac-ft to be released from system reservoirs. Of the 20 ac-ft of inflow to CP-4, 7 ac-ft were passed through the control point to meet the senior right diversion. This amount is the maximum that RES-D may release for the system diversion. Effectively, it is releasing the 7 ac-ft to the senior right, freeing that amount of water for use by the system diversion. Of course, any of the upstream reservoirs RES-A, RES-B, and RES-C may release all of the 12 ac-ft if the storage content is sufficient.

The downstream release constraint is determined on a control point basis. If a second system diversion exists at control point CP-4 that is junior to the first, the amount that RES-D may release for the second diversion is constrained by the amount that RES-D released for the first. If RES-D released 4 ac-ft for the first system diversion, then it is limited to releasing 3 ac-ft for the second because a total of 7 ac-ft were passed through the control point to the senior right. *SIM* maintains an accounting of depletions at and releases to each control point as well as an accounting at each control point of releases made from downstream reservoirs to determine the downstream releases constraints. Negative incremental inflows may cause inaccuracies in the flow accounting.

Tracking Multiple Reservoir System Operations

The input parameter DSS(2) on the *OF* record writes extra simulation results in the *SIM* output DSS file for purposes of tracking the multiple-reservoir release decisions. The following variables are recorded in the DSS file for each reservoir for each month of the simulation: reservoir releases in acre-feet, storage contents in acre-feet, storage contents as a percentage of capacity, and water surface elevation and drawdown in feet for reservoirs with *PV/PE* records.

Storage volumes and water surface elevations are beginning-of-month or end-of-month depending on STOFLG in *JO* record field 11. The DSS file is created at the completion of the simulation. The end-of-month storage and drawdown in the DSS file is at the completion of the water rights priority sequence. The reservoir release computations are based on end-of-month storage within the priority sequence, which typically is not the same as the end-of-month storage at the completion of the priority sequence. The reservoir releases and beginning-of-month storage are the same in the DSS file as the original within-the-simulation priority sequence computations.

The *JO* record parameter SYSOUT creates a *SIM* output HRR file containing hydropower generation quantities and multiple reservoir system releases. The HRR file is read by the *TABLES* HRR record routine and the quantities tabulated in the *TABLES* TOU file in an organized format.

Multiple Rights Associated with the Same Reservoir

Any number of diversion, hydropower generation, or instream flow requirements may be supplied from the same reservoir. A particular reservoir may be assigned to any number of water rights. Storage may be refilled to different levels by multiple rights connected to a reservoir. A particular right may refill storage, divert/release from storage, or both. A reservoir may be the primary reservoir for several rights and a secondary reservoir for other rights.

The water use requirements for each right associated with a reservoir are supplied from the total active storage content of the reservoir below the top of conservation pool of that right

regardless of how the reservoir is refilled. An inactive storage capacity may be specified for each right, from which withdrawals can not be made for that right. However, storage capacity associated with a reservoir is not otherwise allocated among multiple rights in *SIM*. Thus, a senior right may replenish storage depleted by a junior right in previous months. A junior water right could empty its active storage pool, even though the depleted storage capacity affects water available to a senior right at the same reservoir during the next month. However, as discussed below, this issue may be addressed by modeling a shared multiple-owner reservoir as multiple separate reservoirs.

Modeling a Single Reservoir as Multiple Reservoirs

Two or more river authorities, water districts, cities, or other entities may share the same reservoir. If the owners all have equal access to the total storage shared in common, their water use may be aggregated and the reservoir modeled as a single reservoir using the basic *WR* and *WS* record features. However, the reservoir operation problem is more complicated if each entity individually owns or contractually controls a specified portion of the storage capacity in the one reservoir. If each owner has a dedicated storage capacity from which the other owners are not allowed access, the multiple-owner reservoir may be treated as multiple separate reservoirs located at the same control point. Each component reservoir has its own storage capacity, diversion/release targets, and operating rules.

If nonlinearities of the area-volume relationship used in the evaporation computations are not of concern and if the different owners can be assigned different priorities, a single reservoir with multiple owners can be modeled as separate reservoirs easily within *SIM* without having to activate additional special computational methods. However, with net evaporation-precipitation modeled as a nonlinear function of storage, a scheme for its allocation among the multiple reservoir owners is required. Priorities or an alternative allocation scheme are also required to define the order in which the multiple owners have access to inflows to fill their storage and meet their water use requirements. The evaporation allocation *EA* record facilitates allocating the net evaporation-precipitation volumes among the otherwise computationally separate reservoirs. If the rights share the same priority, *AF* record parameters are also provided to allocate available stream flow.

SIM can automatically handle the allocation of the total net evaporation volume between multiple component reservoirs without needing the *EA* record evaporation allocation routines if the following two premises are accepted as being valid.

1. The evaporation volume is allocated between the different entities in direct proportion to their beginning-of-month and end-of-month storage contents.
2. The storage versus area relationship defined by either the *SV/SA* record table or the coefficients on the *WS* record is linear. The storage versus area relationship adopted for each component reservoir is a linear relationship representing the actual single reservoir.

The *EA* record evaporation allocation routine allows a nonlinear storage-area relationship for the actual reservoir to be applied to each of the individual component reservoirs representing different owners and allows specification of alternative strategies for allocating evaporation.

Evaporation Allocation Methodologies Activated by the EA Record

The multiple *computational* reservoirs representing each entity's share of the storage capacity in the single actual reservoir are listed on an evaporation allocation *EA* record along with selection of allocation method. The *computational* reservoirs listed on an *EA* record represent the multiple storage components of the single actual reservoir as illustrated by Appendix C Example 6.

Each component reservoir listed on an *EA* record must be associated with a type 1 or 7 right that refills storage in that reservoir. The evaporation allocation routine is applied only to type 1 or 7 rights. However, any number of type 2, 3, 5, or 6 rights or *IF* record rights may also withdraw or release water from the reservoir. Thus, the evaporation allocation may be associated with essentially any reservoir operating scenario. With multiple rights at the same reservoir, evaporation computations are repeated in the water rights loop priority sequence, with the last computed evaporation volume replacing amounts determined as more senior rights were considered. Thus, the *EA* record evaporation allocation should be performed with the most junior right at each component reservoir, which must be type 1 or 7 rights, controlling the refilling of storage.

Total net evaporation-precipitation volume is computed based on the total area determined as a function of total storage content. Total storage determined by summing the contents of the component reservoirs is combined with a storage-area relationship to obtain the water surface area. Although not required by *SIM*, component reservoirs will normally share the same storage versus area relationship (*SV/SA* records) in the model. A component reservoir's share of the evaporation-precipitation volume is computed by one of the alternative methods listed below.

Option 1. Incremental Based on Water Right Priorities.- As the rights are considered in priority order, the most senior right with a reservoir on the *EA* record is allocated the net evaporation computed prior to considering other junior rights. Each subsequent water right with a reservoir on the *EA* record is allocated its incremental additional net evaporation in the priority sequence. The concept is to determine evaporation unaffected by junior rights in the priority sequence.

Options 2 and 22. Proportional to Storage Content.- The evaporation-precipitation volume is allocated among the component reservoirs in proportion to beginning-of-month storage. If the beginning-of-month storage is zero in all reservoirs, net evaporation associated with refilling during the month is divided equally between the reservoirs. Options 2 and 22 are the same except for the last reservoir.

Options 3 and 33. User-Specified Factors.- The net evaporation-precipitation volume is allocated among the component reservoirs based on multiplier factors entered on an *EF* record. Thus, the model-user defines a fixed proportion for each reservoir. The computations switch to option 2 above if beginning-of-month storage drops below a limiting level specified on the *EF* record. The difference between options 2 and 3 is that the multiplier factors for option 2 are the ratio of beginning-of-month storage content to storage capacity and for option 3 are specified on an *EF* record. Options 3 and 33 are identical except for handling of the last reservoir.

Option 4. Priority Adjusted with Multiplier Factors.- The net evaporation volume is first determined in the same manner as option 1 and then multiplied by a factor from the *EF* record. The computations switch to option 2 above if the beginning-of-month storage drops below a limiting storage level specified on the *EF* record. With factors of 1.0 and no switching limit, option 4 is identical to option 1.

Method (option) 1 models the fundamental principle of a prior appropriation water right priority system. The method 1 computations are based on accumulating storage and evaporation volumes as the simulation progresses through the priority sequence. Component reservoirs associated with junior rights in the priority sequence are not considered when determining the evaporation for a particular more senior water right. Method 4 is a variation of method 1 providing additional flexibility for adjusting the allocation.

Methods 2, 22, 3, and 33 consist of multiplying an estimate of the total net evaporation-precipitation volume by a computed or given factor for each reservoir. With methods 2 and 22, *SIM* computes the factors as the ratio of beginning-of-month storage in each component reservoir to the total for all the reservoirs. With methods 3 and 33, the model-user provides the factors on *EF* records. Options 22 and 33 are identical to options 2 and 3 except for the feature described below.

Since the evaporation allocation computations occur in the water rights priority sequence, end-of-month storage for junior rights has not yet been computed when a particular more senior right is considered. Net evaporation-precipitation volumes are always computed in *SIM* based on an average water surface area determined from both end-of-month and beginning-of-month storage. End-of-month storage is a function of net evaporation, which is a function of end-of-month storage. Thus, an iterative algorithm is required. The evaporation allocation algorithm is integrated into the normal iterative computational procedure described earlier in this chapter for simultaneously determining reservoir outflow, net evaporation, and end-of-month storage volumes. However, in applying the storage-area relationship to determine water surface area, the best estimate of end-of-month storage at that point in the priority sequence calculations is used for the allocation algorithm. For any component reservoir for which end-of-month storage has not yet been computed, the end-of-month storage is estimated as the beginning-of-month storage. In order to ensure that the combined total net evaporation volume is correct, for methods 2 and 3 defined above, the volume for the last reservoir listed on an *EA* record is computed as the final correct total net evaporation-precipitation volume less the amounts previously determined for the other reservoirs.

This option 2 and 3 feature for forcing the evaporation for the component reservoirs to sum to the correct total is not applied with options 22 and 33. With options 22 and 33, all component reservoirs listed on the *EA* record are treated the same, and thus the evaporation volume for the component reservoirs will typically not sum to the correct final total.

With method 1, the correct total evaporation is computed at each point in the priority sequence and the incremental evaporation assigned to the right is determined by subtracting the cumulative incrementals previously assigned to senior rights. Thus, the evaporation for the component reservoirs automatically sum to the correct total. The problem associated with options 22 and 33 that is described in the preceding paragraph is also pertinent to option 4.

Multiple Rights at the Same Component Reservoir

The following are key basic concepts in combining multiple rights at the same component reservoir listed on an *EA* record. With multiple water rights at the same reservoir, diversions and releases associated with senior rights are accumulated in memory and incorporated into the water budget computations associated with the other more junior rights at that same reservoir. In the water right priority sequence simulation, the water accounting

computations for a particular water right includes consideration of the diversions and releases at the same reservoir previously determined for more senior rights. However, the evaporation and end-of-month storage volumes previously computed for any senior rights at the reservoir are not considered. Net evaporation and end-of-month storage volumes are computed again from scratch as each right is considered in the priority sequence. Total hydroelectric energy generation is also recomputed from scratch for multiple hydropower rights at the same reservoir.

The following routines are applied in the water rights simulation when considering a water right located at a reservoir listed on an *EA* record.

1. For type 1 and 7 rights (*WR* record field 6), the net evaporation-precipitation volume is computed based on evaporation allocation methods activated by the *EA* record options outlined in the preceding two pages. The evaporation allocation methods are applied only to type 1 and 7 rights.
2. For hydropower rights, the head used in the hydropower computations corresponds to the summation of the storage contained in all of the component reservoirs listed on the *EA* record. Likewise, the elevation of the bottom of the power pool refers to total storage capacity summed for all the reservoirs. Storage in all *EA* record reservoirs is summed in the computation of head and specification of bottom of power pool for all hydropower rights. However, the *EA* record evaporation allocation routines are not applied for hydropower rights. Evaporation is determined by the conventional *SIM* routine.
3. The stream flow availability allocation routine activated by the *AF* record is applied to all water rights associated with all reservoirs listed on the *EA* record. Storage and evaporation are not relevant to the *AF* record stream flow availability routine.

The *EA* record evaporation allocation routines are activated within *SIM* only for type 1 and 7 rights. However, with caution, any number of water rights of any of the types can be applied at *EA* record reservoirs. Evaporation allocation options 2, 3, 22, and 33 are different than options 1 and 4 in regard to dealing with multiple rights at the same component reservoir.

Reservoir storage is filled only by types 1, 5, and 7 rights (*WR* record field 6). Thus, with or without *EA* records, every reservoir must have at least one type 1, 5, or 7 water right or the reservoir will never refill. Typically, with multiple rights at the same reservoir, the most junior right will be a type 1 right that performs the final refilling in the priority sequence. Likewise, for *EA* record reservoirs, the final evaporation allocation typically will be determined with a type 1 right at each reservoir listed on the *EA* record.

Since with or without *EA* records, type 2 and 3 rights do not refill storage, the final end-of-month storage is yet unknown, and evaporation volumes are approximate. Since type 2 and 3 rights do not activate the *EA* record routine, water surface areas determined from the nonlinear storage-area relationship are approximate. The degree of inaccuracy depends on the nonlinearity of the storage-area relationship. This evaporation volume is used only in the determination of the amount of water available to the right from reservoir storage. The evaporation affects the diversion only if the reservoir empties. The actual final evaporation volume for the reservoir should be determined later in the priority sequence in association with a type 1 right that activates the *EA* record evaporation allocation routine.

Likewise, the evaporation volume computed for hydropower rights is approximate, but serves only in the determination of the amount of water available to the hydropower right from reservoir storage if followed in the priority sequence by a type 1 or 7 right. However, as a separate issue for hydropower rights, *SIM* uses the total storage summed for all the *EA* record reservoirs in the determination of head and minimum power pool elevation.

Evaporation allocation options 1 and 4 are based on incremental evaporation volumes. With options 1 and 4, storage and evaporation volumes are accumulated. The evaporation computed for the most senior component reservoir treats the other junior component reservoirs as not existing. Thus, there must be a priority sequence with one type 1 or 7 water right at each *EA* record reservoir. For example, with three reservoirs listed on an *EA* record, there must be exactly three type 1 or 7 water rights representing the three reservoirs. There can not be two type 1 rights at the same reservoir interrupting the priority sequence storage and evaporation volume accumulation. There can be any number of complete sets of three type 1 or 7 rights as long as there is no intermingling between the sets of three rights in the priority sequence. Any other types of rights at the *EA* record reservoirs should be senior to the type 1 and 7 rights driving the evaporation allocation algorithm. These option 1 and 4 requirements are not applicable for options 2, 22, 3, and 33.

Options 2 and 3 use the last reservoir listed on the *EA* record to assure that the evaporation for the component reservoirs sum to the correct total for the actual real reservoir. Thus, a type 1 or 7 right junior to all the other rights associated with the *EA* record reservoirs must be assigned to the last reservoir listed on the *EA* record. This requirement is not applicable to options 22 and 33. Options 22 and 33 are the most flexible of all the evaporation allocation options in dealing with multiple rights at the same component reservoirs.

Allocation of Available Stream Inflow to the Reservoirs

Water right priority numbers set the order in which rights are considered in the computations and thus have access to available stream flow. However, two or more of the reservoir owners may share the same priority. With multiple rights having the same priority, an alternative methodology is adopted to allocate available flow between water rights. The *AF* record serves this purpose. With the *EA/AF* record option activated, the amount of stream flow available to a water right is determined in the water rights priority loop computations as follows. If the parameters *MIN* and *MAX* are not used, the algorithm consists simply of multiplying the available stream flow by the factor *AFX* from the *AF* record.

- The available stream flow volume (A_1) is first determined in the normal manner and then adjusted by the *AF* record parameters as follows.
- If the minimum limit (input parameter *MIN*) is not zero, the adjusted available stream flow is set at A_1 as long as A_1 does not exceed *MIN*.
- If A_1 exceeds *MIN*, an input multiplier factor *AFX* is applied as follows
$$\text{adjusted available stream flow} = \text{MIN} + (A_1 - \text{MIN}) \times \text{AFX}$$
- If maximum limit (input parameter *MAX*) is not zero, the adjusted available flow is set at *MAX* if the volume computed by the equation above exceeds *MAX*.

The *AF* and *AX* records both serve the same purpose and are based on the same simulation algorithm. The stream flow availability allocation factors *AFX* record connected to the *EA* record is designed for modeling multiple-owner reservoirs. The flow availability *AX* record connected to the priority circumvention *PX* record discussed in the last section of this chapter can be more generically applied to any water right. The *PX/AX* option allows allocation factors to vary monthly throughout the year, while the *EA/AF* option is limited to a constant factor for the entire year.

Dual Simulation Capabilities

The basic concept of the dual simulation feature is to establish a set of stream flow depletions for selected water rights during an initial simulation representing a specified water management scenario, which then serve as upper limits on the stream flow available to those rights during a second simulation reflecting an altered or different water management scenario. Without the automated dual simulation, *SIM* may be executed once to develop a set of stream flow depletions, which are then incorporated into a *SIM* input file as time series *TS* records for use in further simulations. The dual simulation options automate the repeat of the simulation.

Multiple Diversion Rights Supplied by the Same Reservoir

The dual simulation options are designed primarily for applications where multiple rights with different priorities divert water from the same reservoir system. Without the dual simulation, reservoir draw-downs associated with junior diversions may be inappropriately refilled in subsequent months by senior rights at the same reservoir. The set of dual simulation options allow stream flow depletions computed during an initial simulation to be used as upper limits constraining depletions during a second simulation. Selected water rights may be switched on or off during either the initial or second simulations. The two simulations are performed automatically during a single execution of *SIM*.

The dual simulation feature is designed to preserve the priority system by preventing actions of junior rights in a current month from adversely affecting more senior rights in future months through the delayed effects of reservoir storage draw-downs and refilling. Without the dual simulation options, reservoir draw-downs associated with junior diversions may be refilled in subsequent months by senior rights at the same reservoir. For example, junior diversion right *XX* draws the reservoir down in July. During August, senior right *YYY* at the same reservoir refills storage with stream flow that otherwise would have supplied other third-party rights with priorities falling between the priorities of senior right *YYY* and junior right *XX*. Thus, the diversion by junior right *XX* from reservoir storage in July results in other senior third-party rights having stream flow availability inappropriately reduced in August and later months when senior right *YYY* refills the reservoir.

With activation of the dual simulation option, an initial simulation is made without junior right *XX* to determine the proper stream flow depletions during each month of the period-of-analysis for senior right *YYY*. The dual simulation option allows the senior right *YYY* stream flow depletions computed during the initial simulation without junior *XX* to be used as upper limits constraining senior right *YYY* depletions during a second simulation in which junior right *XX* is also activated. An additional junior *WR* record may also be added to allow senior right *YYY* to further refill storage with excess flows not appropriated by any other rights.

Dual Simulation Options

The dual simulation options are activated for individual water rights as specified by either *PX* record field 2 or *SO* record field 14. A default dual option may be set for all rights by *JO* record parameter *DUALD*, subject to being over-ridden for individual rights by the *SO* or *PX* records. The *RG* record can be used to assign the same *PX* record parameters to groups of rights as described later in this chapter.

The *DUAL* simulation options available for application to one or any number of water rights are as follows.

- Option 1: The water right is activated only during the initial simulation.
- Option 2: The water right is activated only during the second simulation and is not subject to an initial simulation stream flow depletion constraint.
- Option 3 with variations 33 and 333: A dual simulation is automatically performed. Stream flow depletions computed during the first simulation serve as upper limits on water availability during the second simulation. The stream flow depletions computed during the initial simulation may optionally be written to the message file.
- Option 4: The water right is activated only during the initial simulation. A stream flow depletion array is developed. If an option 5 right follows this right, the depletions serve as upper limits on water availability for the option 5 right during the second simulation. The stream flow depletions may optionally be written to the message file.
- Option 5 with variations 55 and 555: A dual simulation is performed with this water right being activated only during the second simulation. The stream flow depletion array from the preceding option 4 right serves as an upper limit on depletions for this option 5 right.

A second simulation is automatically performed if and only if option 3 or 5 is selected for one or more rights. Alternatively, the simulation may be performed once to develop a set of stream flow depletions, which are then incorporated into an input file as *TS* records for use in further simulations. Options 3 and 4 depletions may also be written to the message file.

With dual options 3 and 5, stream flow depletions each month for a right determined during the first simulation serve as a maximum limit on stream flow depletions during the second simulation. The stream flow depletion for a given month during the second simulation is not allowed to exceed the depletion for that month occurring during the initial simulation. Options 33, 333, 55, and 555 are variations of options 3 and 5 that allow the depletion constraints to be relaxed somewhat by allowing flexibility in the timing of the depletions.

Dual options 33 and 55 are the same as options 3 and 5 except the constraints applied during the second simulation are based on cumulative stream flow depletions rather than depletions in each individual month. For any month, for a particular right, the total cumulative stream flow depletions since the beginning of the second simulation can not exceed the corresponding cumulative depletions occurring in the initial simulation.

With options 333 and 555, for water rights that refill reservoir storage (types 1, 5, and 7 rights as indicated in Table 4.1), the limit during the second simulation is the accumulative

stream flow depletions since the reservoir was last full. During the second simulation, the accumulation of initial simulation depletions is zeroed any time the reservoir contents are full to capacity. For other water right types, the options 333 and 555 limits applied during the second simulation are the first simulation depletion for the current month plus any excess depletion from the immediately preceding month. Unused stream flow depletions below the constraining limits are carried into the next month but no further.

Options for Circumventing the Priority Sequence

As discussed throughout this manual, the *WRAP-SIM* modeling strategy is based on simulating water development/management/allocation/use in a priority-based water rights computational sequence. In general, senior rights affect the amount of water available to junior rights but are not affected by the junior rights. However, in some applications, various needs may arise for evading the priority sequence. For example, as previously discussed, same-month return flows from water supply diversions from storage associated with a junior right are not available to senior rights located downstream but should be. The next-month diversion return flow option is designed to address this issue. Likewise, the next-month hydropower option allows senior rights access to hydropower releases. Second pass instream flow *IF* record options involving a repeat of the water rights loop within a given month are discussed in the preceding section.

Reservoir storage priority complexities, multiple rights with the same priority, agreements that subordinate a senior right to a junior right, and various other aspects of water management may motivate circumvention of the water right priority loop sequencing in the simulation computations. Different sets of options activated by the priority circumvention *PX* record and stream flow availability factor *AX* record are designed to facilitate evasion of the normal *SIM* priority sequence based allocation of available water. The options may also serve other purposes not necessarily related to evading the restrictions of the priority system. The different *PX* record options may be applied either independently or in combination with each other and combined with various other *SIM* features. Strategies for their use are governed by the water management situation being modeled and the ingenuity and creativity of the model-user.

The *PX* record described in the *Users Manual* provides the following four different types of modeling features which are described as follows.

1. The dual simulation feature described in the preceding section is actually designed to contribute to maintaining the priority system though discussed here in the context of *PX* record options. A set of dual simulation options allow a repeat of the simulation for the entire hydrologic period-of-analysis. Water rights may be selected for activation or deactivation during either the first or second simulation. [*JO* record field 16, *PX* field 2, *SO* field 14, or *RG* record field 4]
2. For multiple rights sharing the same priority, the allocation of available stream flow may be based on parameters provided as input. [*PX* record field 3 and *AX* record]
3. All downstream control points are normally considered in both determining the amount of water available to a right and adjusting water availability for the effects of the right. A downstream control point limit option allows the model-user to adjust the manner in which these computations cascade downstream. [*PX* record fields 4 and 5 or *RG* fields 5 and 6]

4. Transient priority XP options allow a computational water right to be activated and deactivated at different points in the priority sequence. The simplest XP option allows a return flow to occur later in the priority sequence than the corresponding diversion. A second more complex XP option allows all features of a water right to be activated and deactivated at different points in the computational sequence based on two different assigned priorities. [*PX* record fields 6–12]

Dual Simulation Feature

The *SIM* dual simulation options described in the preceding section of this chapter were originally motivated primarily by applications where multiple rights with different priorities divert water from the same reservoir. The dual simulation feature allows stream flow depletions determined during an initial simulation to serve as upper limits on flow depletions during a second simulation. Selected water rights may be activated or deactivated during either of the two simulations. The basic concept of the dual simulation feature is to establish a set of stream flow depletions for selected water rights during an initial simulation representing a specified water management scenario, which then serve as upper limits on the stream flow available to those rights during a second simulation reflecting an altered or different water management scenario.

Allocation of Available Stream Flow

A fundamental concept of *WRAP-SIM* is that available stream flow is allocated to each water right in turn in the water rights computation loop priority sequence. Since the computational procedure is based on considering water rights one at a time, for purposes of sequencing rights in the computations, no two rights can be assigned the same priority. However, water rights actually having the same priority and located at the same control point or different control points with access to approximately the same stream flow may be modeled as adjacent rights in the priority sequence with the available stream flow allocated between them based on user-specified parameters entered on the *PX* and *AX* records.

Water right priorities govern access to available stream flow. However, when multiple water rights have the same priority, another strategy must be adopted to allocate available stream flow between the rights. The *PX* record stream flow availability allocation option uses multiplier factors. Either a constant multiplier factor may be entered on the *PX* record or factors for each of the 12 months of the year may be entered on *AF* records. The amount of stream flow available to a right is first determined in the normal manner and then multiplied by the pertinent factor from the *PX* or *AX* record. The model-user must select appropriate multiplier factors.

For example, consider a water management situation in which three *WR* record diversion and/or storage rights located at the same control point have equal access to available stream flow. One-third of the available flow is to be allocated to each water right. The three rights are assigned priorities allowing them to be adjacent in the priority sequence. The most senior right is assigned a multiplier factor of 0.33333 on the *PX* record, allowing it access to one-third of the available stream flow. The second right is assigned a factor of 0.50 allowing it access to half of the remaining two-thirds of the available stream flow. The most junior of the three rights is assigned a factor of 1.0 allowing it access to the remainder of the available stream flow.

The methodology is explained in the *Users Manual*. The same available stream flow allocation procedure is also implemented by an *EA/AF* record option described earlier in this chapter in the section on multiple rights associated with the same reservoir.

Downstream Control Point Limit

As outlined in Figure 2.2 of Chapter 2, the *SIM* simulation is organized based on a water rights priority loop embedded within the monthly time step loop. Within the water rights priority loop, as each individual right is considered in turn, the computations are performed in four stages.

- Task 1: A water supply diversion, hydropower generation, or other type of target is set.
- Task 2: The amount of stream flow available to the right is determined. Stream flow availability is determined as the lesser of the stream flow availability array amounts at the control point of the water right and at each of the control points located downstream.
- Task 3: Water volume balance computations are performed to compute the stream flow depletion, net reservoir evaporation, end-of-period storage, return flow, diversion and diversion shortage, and hydroelectric energy generated and shortage.
- Task 4: The stream flow availability array values at the control point of the water right and at downstream control points are decreased by a flow depletion and increased by a return flow or hydropower release, with adjustments for channel losses or loss credits.

The simulation begins with the stream flow availability array consisting of naturalized flows at each control point. The array of flows is adjusted (task 4) for the effects of each water right in turn. At any point in the priority sequence, the stream flow availability array provides an account of the volume of flow still available after considering all rights that are more senior.

Task 1 consists of determining the amount of stream flow that is available to the water right. For example, assume that junior water right JJJ located at control point CP-1 in Figure 4.4 is being simulated in the priority sequence. The volume of stream flow available to right JJJ is the lesser of the amounts in the stream flow availability array at control points CP-1, CP-3, CP-4, and CP-5. Stream flow depletion by senior right SSS at CP-4 may have resulted in the available flow at CP-4 and/or CP-5 being less than at CP-1. This means that all or a portion of the flow at CP-1 has already been committed for senior right SSS. Junior right JJJ does not have access to that flow at CP-1 and must let it pass through.

The purpose of the *PX* record control point limit option is to circumvent the basic concept of stream flow availability being affected by flows at all downstream control points. The feature may be used to model the removal of requirements for pass-through of flows for downstream senior rights. The control point limit option alters tasks 2 and 4. Without this option, the control point of the water right and all downstream control points are considered in tasks 2 and 4. The option is activated by specifying a control point located downstream of the control point of the water right. This control point and any control points located downstream are removed from consideration in task 2. Task 4 adjustments to the stream flow availability array at and below the *PX* record control point are also altered.

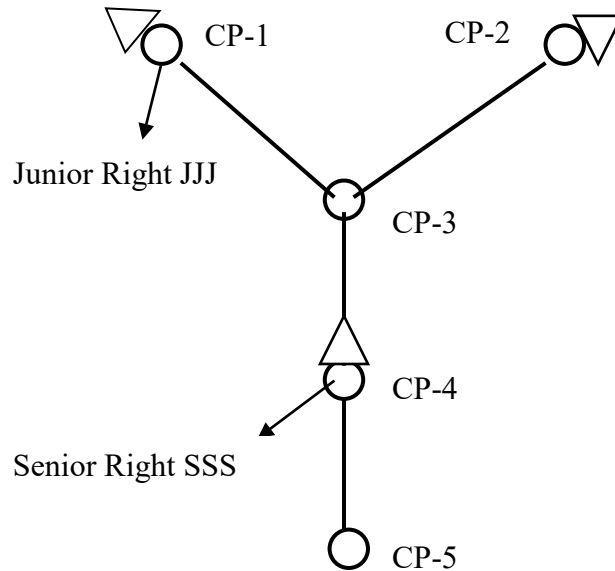


Figure 4.4 System Schematic for Example 10 in Appendix C

The control point identifier *XCPID* is entered on the *PX* record associated with a particular water right. The water right of the *PX* record is not constrained by the effects of any other water rights on flows at *XCPID* and other control points located downstream of *XCPID*. As the water right is modeled in the priority sequence, the simulation computations are altered in the following two ways.

1. Control point *XCPID* and control points downstream of *XCPID* are not considered in determining stream flow availability (Task 1). An increase *XAV* in the amount of stream flow available to the right may result. An option limits the maximum increase in available stream flow to not exceed flow depletions by senior rights at *XCPID*. Optionally, only *XCPID*, not other downstream control points, may be excluded in the determination of stream flow availability.
2. The increase in stream flow depletion, with appropriate channel loss adjustments is omitted in the Task 4 adjustments of the stream flow availability array at control point *XCPID* and at control points located downstream of *XCPID*.

Increases in water availability *XAV* each month are written to the *SIM OUT* file. *XAV* is zero unless flows at or downstream of *XCPID* are controlling stream flow availability for the right in that month. If flows at or downstream of *XCPID* are controlling stream flow availability, ignoring the control point results in an increase in water availability which may result in an increase in the stream flow depletion by the water right.

The *PX* record control point limit feature will work with any of the negative incremental flow options specified in *JD* record field 8, but caution should be exercised if applied with options 1 or 5. The *PX* record feature is based on the following basic concept. The effects of senior water rights are the reason that stream flow availability for a water right may be governed by flows at downstream control points in some months. Physically, the water right may have to

curtail depletion of stream flow so that flows available to downstream senior rights are not reduced. With negative incremental flow options 2, 3, or 4, senior rights are the only reason for stream flow availability to be controlled by flow at downstream control points rather than at the control point of the water right. However, with negative incremental flow options 1 and 5, negative incremental naturalized flows may also affect stream flow availability for water rights located upstream. Option 5 may particularly complicate the simulation in this regard.

The manner in which the *PX* record control point limit options are applied depends on the particular water management situation being modeled and the preferences of the modeler. For example, as discussed above, the feature may be used to prevent stream flow available to an upstream junior right from being diminished by a subordinated senior right. This particular type of application and modeling strategy are discussed below. Other types of applications are possible as well.

Combining Features to Model a Subordination Agreement

Example 10 of Appendix C illustrates the following general modeling strategy in which *PX* record control point limit and dual simulation features and a *BU* record backup right are combined to simulate a subordination agreement. Referring to Figure 4.4, water right JJJ at control point CP-1 is junior to water right SSS at CP-4. However, a subordination agreement has been executed stating that contrary to the normal prior appropriation water right permit system in effect in general, as an exception, water right JJJ is not required to curtail diversions or storage to pass inflows through its reservoir to maintain stream flows for senior right SSS. The agreement is not applicable to the other water rights at various locations in the river basin, some of which have priorities falling between those of senior right SSS and junior right JJJ.

With CP-4 specified for *XCPID* on the *PX* record for junior right JJJ, its stream flow availability is not affected by the requirement to pass flow through CP-1 for senior right SSS at CP-4. Since in the model senior right SSS has already made its stream flow depletion, junior right JJJ is appropriating water that is not available. Thus, there is an excess appropriation. In performing task 4, *SIM* omits the portion of the junior right JJJ stream flow depletion that is an excess appropriation, adjusted for channel losses, from the stream flow availability array adjustments at and below the *PX* record control point *XCPID*.

Thus, the *PX* record control point limit option allows junior right JJJ to appropriate stream flow without being constrained by senior right SSS. Stated more precisely, junior right JJJ is not constrained by the effects of any other water rights on flows at CP-4 and the downstream CP-5. However, a problem occurs in that the junior right JJJ stream flow depletion may include an amount over the volume of stream flow that is actually available. The excess stream flow depletion amount at CP-1 is reduced by channel losses to an equivalent amount at CP-4. The strategy described below for dealing with the excess stream flow depletion uses the backup right option activated by a *BU* record. With reservoir storage associated with senior right SSS, the dual simulation option may also be activated to protect other water rights.

A new water right is created for the sole purpose of serving as a backup right to account for the excess stream flow depletion *XD2*. The backup right is junior to junior right JJJ, is located at control point CP-4, and diverts from the same reservoir as senior right SSS. If storage

is sufficient, the *XD2* results in a draw-down of the reservoir. Otherwise, a diversion shortage is declared which represents a diversion shortage to be incurred by senior right SSS. A *BU* record backup right normally adds a shortage incurred by another right to its target. However, with a *BU* record combined with the *PX* downstream control limit activated for a right, *WRAP-SIM* adds the excess stream flow depletion, instead of shortage, to the target of the backup right.

Assume the procedure outlined above results in a drawdown in reservoir storage in June to mitigate the junior right JJJ excess stream flow depletion. This means that a certain volume of stream flow was appropriated by junior right JJJ at CP-1 rather than passing the flow on down to senior right SSS. Thus, senior right SSS's reservoir is lower than it would have been otherwise at the end of June. Other rights not bound by the subordination agreement may be affected when senior right SSS refills its reservoir in July or some later month. This is the complexity discussed in the prior section describing the dual simulation feature. The dual simulation feature is activated to address this concern. An initial simulation without the *PX* record control point limit feature and *BU* record backup feature activated establishes a sequence of stream flow depletions for senior right SSS that serve as upper limits in the second simulation.

Application of the dual option may possibly limit access of water right SSS to unappropriated stream flows. A *WR/WS* record type 1 reservoir refilling right junior to all other rights may be added to capture any remaining available flow at the end of the priority sequence.

The strategy for modeling this particular type of subordination agreement situation is summarized as follows.

- Step 1: The *PX* record control point option prevents the stream flow available to an upstream junior right from being diminished by a subordinated senior right located downstream.
- Step 2: Step 1 above may result in an increase in stream flow depletions by the upstream junior right that must be mitigated by the subordinated senior right. A junior backup *BU* record right is created for this purpose. The incremental addition in stream flow depletion by the junior right is treated as a diversion target by the backup right. The backup right may supply its diversion target from the reservoir of the subordinated senior right. Diversion shortages incurred by the backup right are treated as diversion shortages associated with the subordinated senior right.
- Step 3: Step 2 above may result in drawdown of reservoir storage in the reservoir of the subordinated senior right. Refilling during future months may inappropriately affect other rights that are not connected to the subordination agreement. The *PX* record dual simulation capability is adopted to deal with this complexity.
- Step 4: Step 3 could result in constraining the filling of the senior right's reservoir more than necessary. There could possibly be unappropriated stream flows to which the senior reservoir is inappropriately denied access. This problem may be partially addressed by adopting dual simulation options 33, 333, 55, and 555 described in Chapter 2. Alternatively, an extra right junior to all other pertinent rights may be added solely to refill storage with any unappropriated stream flow that may still be available after considering all relevant water rights.

The strategy outlined above for modeling subordination agreements is designed to prevent third-party rights from being affected, including by actions in a current month causing effects in future months through reservoir storage draw-down and refilling. However, other aspects of the simulation may still result in third-party rights being affected. Next-month return flows and next-month power releases circumvent the priority sequence. Next-month return flows and next-month power releases associated with rights either connected or unconnected to the subordination agreement rights may cause third-party rights to be affected by the subordination. Target setting options applied for third-party rights based on stream flows or storage likewise complicate the simulation in this regard.

The objective of the strategy outlined above is to model agreements between certain parties to circumvent the priority system without affecting other third-party water users. The difficulty is that in complex real-world river/reservoir systems, water management actions have unintended consequences. Modeling studies may very well involve attempts at preventing effects of certain actions on third parties in the simulation model that can not be prevented in the real world. Thus, these types of modeling strategies must be applied with caution.

Transient Water Right Options

The *PX* record transient water right features provide additional capabilities for circumventing the water right priority sequence. A *WR/PX* record combination creates a pair of computational water rights. The first and second components of the water right duo are assigned priorities from *WR* field 5 and *PX* field 8, respectively. The *PX* record activates two types of dual switching priority (*XP*) water rights. The first type assigns a priority to return flows that is different than the diversion priority. The second involves activation and deactivation of an entire water right at different points in the priority sequence. This potential modeling strategy has not been thoroughly tested and should be applied with caution with applied at all.

With *XP* option 1, return flows may occur at points in the priority loop sequence different than the corresponding diversion. This option may be used to control which other rights have first access to return flows based on the priority placement of the return flows. The second internal component right does nothing but the return flow. If the return flow priority entered in the *PX* record is junior to the priority in the *WR* record, the return flow occurs in the same month as its diversion. Otherwise, the return flow occurs in the next month which is the next time its priority is reached in the priority based simulation computations.

PX record *XP* option 2 is motivated by subordination agreements designed to evade the priority system. A computational right is activated and deactivated at different points in the computations based on assigned priorities. The objective is to constrain water availability for other rights bracketed by the two priorities. A right is activated based on the senior priority from its *WR* record. Its stream flow depletion, return flow, and storage change are later reversed automatically within the model as a second component right at a priority from the *PX* record. Stream flow depletions are returned to the stream as return flows. Return flows are reversed as stream flow depletions. In typical subordination applications, the actual water right will be modeled with another *WR* record with its actual junior priority. The mechanisms of applying these options are explained in the *Users Manual*.

Artificial Control Points, Water Rights, and Reservoirs

Designation of control points, water rights, and reservoirs as being "*artificial*" does not affect the *SIM* simulation computations. The sole purpose of the designation of artificial is to exclude certain quantities from the simulation results output OUT, CRM, SOU, and DSS files. Quantities for artificial control points, *WR* record water rights, and reservoirs are included in the *SIM* output files only if certain output options controlled by the *JD* record are activated.

Although the artificial feature for controlling output datasets can be generically used whenever convenient for various purposes, a primary motivation for its addition to WRAP is to clarify simulation results and reduce confusion that may be caused by water accounting schemes employing artificial or "dummy" control points and related model components. These types of mechanisms have been incorporated in several of the Texas Water Availability Modeling (WAM) System WRAP input datasets for purposes of various accounting computations. Water is diverted to and from and stored in accounting reservoirs that serve computational purposes but do not represent actual physical reservoirs. Ingenuity and creativity can be employed to devise various such accounting mechanisms. These types of artificial modeling components complicate input datasets and simulation results and should be used sparingly and cautiously if at all.

Many of the tables developed with *TABLES* can be misleading or meaningless when combining artificial accounting and regular simulation quantities from *SIM* simulation output files. The artificial designation feature provides a remedy for preventing confusing *TABLES* tables organizing *SIM* simulation results. Quantities associated with selected artificial control points, water rights, and reservoirs are removed from the aggregation of simulation results. *SIM* input DAT file datasets are also clarified by the explicit identification of artificial components.

Any number of the control points, *WR* record water rights, and reservoirs in a *SIM* input DAT file can be classified as artificial as described in the *Users Manual*. The ARTIF parameter on the *CO* and *WO* records allow control points and water rights to be classified as artificial as follows. The *CO* record ARTIF parameter is the only way to designate a control point as artificial. All water rights and reservoirs located at an artificial control point are automatically designated by *SIM* as being artificial.

Labeling control points, water rights, and reservoirs as artificial does not affect the *SIM* simulation computations or regular "non-artificial" simulation results. Reservoir storage volumes, diversion and return flow volumes, and all other quantities associated with artificial control points, water rights, and reservoirs are separated from quantities associated with regular control points, water rights, and reservoirs for purposes of recording output records in the OUT and CRM files read by *TABLES* and also in the SOU and DSS output files. Options provide flexibility in excluding or including selected output. As *SIM* writes control point, reservoir, and water right output records, those labeled artificial can be omitted or included as desired.

Water Rights Grouping RG Record Capabilities

The *RG* record identifies all water rights that fit one or more specified criteria. A water right is included in the group defined by a *RG* record only if each and every selected criterion is

satisfied by that right. Any number of *RG* records can be included in a *SIM* input DAT file defining different groups. The *RG* record grouping of water rights serves the following purposes.

- The values for the parameters for the dual simulation and downstream control point flow availability options described in the preceding section can be assigned to all rights included in the group. This provides a convenient means for using one *RG* input record to assign values for these parameters to a large number of rights without preparing individual *PX* records for each water right.
- The *WR/IF* record field 5 priority numbers for all water rights in the selected group can be replaced with a single priority. For example, the selected group of rights can be made junior or senior to the other rights.
- A selected group of water rights may be omitted from the simulation. The selected rights are skipped over in the priority sequence simulation computations. This option can be applied for various purposes. For example, a subordination agreement can be modeled by develop streamflow depletions for a certain right without the effects of the selected group.
- Several *TABLES* routines deal with simulation results for groups of water rights in the *SIM* datasets which are defined by group identifiers. Two optional water right group identifiers can be assigned to water rights by entering identifiers in the appropriate fields of each individual *WR* or *IF* record. Alternatively, a group identifier can be assigned by the *RG* record to all water rights in a defined group.
- Information describing the selected water rights can be listed in the message MSS file. Thus, in working with a large *SIM* input dataset, water rights meeting certain criteria of interest can be conveniently identified and viewed.

The following types of criteria for defining groups of water rights can be specified on a *RG* record.

- either *WR* record or *IF* record rights or both types
- water right type specified on *WR* record
- lower and upper limits on the annual target amount specified on *WR* or *IF* record
- lower and upper limits on reservoir storage capacity specified on *WS* record
- lower and upper limits on the priority number specified on *WR* record
- inclusion or exclusion of groups defined by *WR* record group identifiers
- location of the water right in a specified river reach or subbasin

River reaches or subbasins are delineated by specifying downstream and upstream control points. The larger WAM System datasets for which the *RG* record is designed contain hundreds of control points. However, Figure 4.5 provides a simple example with 12 control points. With control point 7 of Figure 4.5 specified on the *RG* record as the downstream control point limit and no upstream limits specified, the group includes water rights located at control points 1, 2, 3, 4, 5, 6, and 7. With control point 4 as the downstream control point limit and no upstream limits specified, the group includes water rights located at control points 3 and 4. With

control points 2, 5, and 9 specified as lower limits but no upper limits specified on the *RG* and *RG2* records, the group includes water rights located at control points 1, 2, 3, 4, 5, 8, and 9.

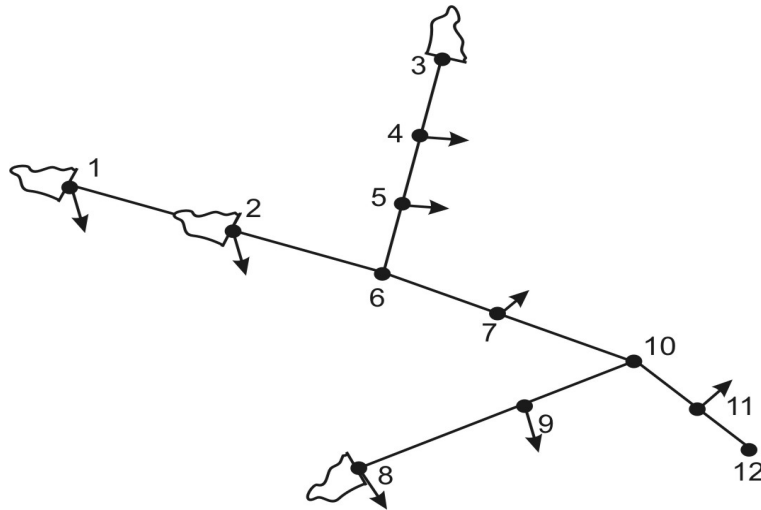


Figure 4.5 Control Point Schematic of Reservoir/River System

The following options are provided by the *RG2* record for defining upstream limits.

1. listing of control points at which the water right cannot be above
2. listing of control points of which the water right must be at or below at least one

Assume that the downstream control point limit in Figure 4.5 is control point 10 and the upstream limits are listed on the *RG* record as being control points 2 and 9. With option 1 above for defining upstream limits, the group contains all water rights located at control points 2, 3, 4, 5, 6, 7, 9, and 10. Water rights at control points 1, 8, 11, and 12 are excluded from the group. With option 2 for defining upstream limits, the group contains all water rights located at control points 2, 6, 7, 9, and 10. Control points 3, 4, and 5 met the option 1 upstream limit criterion but do not meet the option 2 upstream limit criterion.

Period-of-Analysis Input Sequences of Water Right Targets, Stream Flow Depletions, and Reservoir Storage Capacities

SIM options allow time series quantities for certain variables normally computed by the simulation model to be entered on *TS* records or other input types of input records rather than computed. These variables include diversion and instream flow targets, limits on stream flow depletions, and reservoir storage capacity limits. Time series quantities may be computed in either a monthly *SIM* simulation or daily *SIMD* simulation and incorporated into a monthly *SIM* input dataset. The results of a daily *SIMD* simulation are recorded both as daily time series variables in a DSS or sub-monthly (daily) SUB output file and as time series of monthly totals of the daily quantities in a DSS or monthly OUT output file.

Target series *TS* records with water right targets or maximum limits on stream flow depletions created by a *SIM* simulation can be converted to *SIM* input data stored in DSS input

file, the DAT file, or a target series input file with the filename extension TSF. *SIM* simulation results recorded by *SIM* in a DSS output file can also be easily converted to DSS records in a *SIM* simulation DSS input file. DSS files are very convenient for managing large datasets of time series data. The program *HYD* includes options for reading a *SIM* or *SIMD* output OUT file and recording simulation results in a new file created by *HYD*. Thus, *HYD* conveniently facilitates creating a TSF file or other file containing *SIM* or *SIMD* simulation results which is read by *SIM* as an input file. *SIM* input hydrologic condition *HC*, target options *TO*, flow switch *FS*, cumulative volume *CV*, and stream flow depletion limits *LO* records also include options for incorporating any time series read from hydrologic index HI records in a DSS or HIS file into the water right target building process.

Water Right Targets

Water supply diversion and reservoir storage targets associated with a water right *WR* record or instream flow targets associated with a *IF* record may be provided in a *SIM* input DAT file on target series *TS* records or alternatively on *TS* records in a DSS or TSF file. Example 5 in Appendix C includes *TS* records for instream flow and diversion requirements. Targets on *TS* records are input for each month of the simulation. This feature allows quantities computed in a prior simulation or observed gaged data to be entered as fixed targets rather than computed within the *SIM* simulation. The input *TS* record target sequences can also be combined with other *SIM* features for setting targets.

Environmental Instream Flow Targets

Environmental flow targets can be computed more accurately in a *SIMD* daily simulation than in a *SIM* monthly simulation. *SIMD* includes a routine for modeling daily environmental pulse flow requirements that is not included in the monthly *SIM*. Daily environmental flow targets computed in a daily *SIMD* simulation can be aggregated to monthly totals within *SIMD* for inclusion in a monthly *SIM* input dataset. These environmental flow target datasets are conveniently and efficiently managed in DSS files.

Hydrologic Index

The hydrologic index *HI* records contained in a DSS hydrology input file or alternatively a hydrologic index series *HIS* file are used by hydrologic condition *HC*, target options *TO*, flow switch *FS*, cumulative volume *CV*, and stream flow depletion limits *LO* records in the target setting process. Any type of target could be determined as a function of a hydrologic index in a *SIM* or *SIMD* simulation by applying this optional feature. However, the *HI* record and *HIS* file were originally added to *SIM* and *SIMD* to compute *IF* record environmental instream flow targets based on a hydrologic index such as the Palmer hydrologic drought index.

Maximum Limits on Stream Flow Depletions

A period-of-analysis sequence of limits on stream flow depletions may also be entered on *TS* records. The values may vary in each month of the simulation. This feature allows the combined diversion and storage refilling amounts allowed for a particular water right to be

limited to not exceed amounts determined by a prior simulation reflecting specified conditions of water resources development, management, and use.

Subordination agreements are discussed in an earlier section of this chapter (pages 161-163). Modeling of subordination agreements could involve simulations omitting certain water rights that generate period-of-analysis series of streamflow depletion limits that are incorporated in a SIM input dataset as *TS* records. The procedure for modeling subordination agreements outlined in the preceding section of this chapter incorporates this concept.

Reservoir Storage Capacity Limits

Reservoir storage capacity limits may be entered in the *SIM* input DAT file as observed storage *OS* records, which are designed primarily for use in adjusting gaged stream flows to develop naturalized flows as described in the *Hydrology Manual*. Sequences of actual observed storage levels or storage volumes computed in a prior simulation are entered on *OS* records.

OS records provide storage volumes for each individual month of the hydrologic period-of-analysis for a particular reservoir. In each month of the simulation, as each water right is considered in the priority sequence, the storage capacity of the reservoir is the lesser of the storage capacity specified for the water right on its *WS* record and the volume specified for the reservoir on its *OS* record. The reservoir is filled to the capacity defined by the *WR/WS* and *OS* records subject to being constrained to the amount of stream flow available for filling. The end-of-month storage volume contained in the reservoir is limited to not exceed its capacity. Excess storage is released as a spill which is cascaded downstream just as any other reservoir release.

The features activated by observed storage *OS* records and the monthly storage *MS* record described earlier in this chapter are similar with certain distinct differences. Both the *MS* and *OS* records set monthly-varying limits on reservoir storage capacity. In each month of the simulation, as each water right is modeled, the reservoir storage capacity is the lesser of the volume set by the *WR/WS* records for the water right and the *MS* and/or *OS* records for the reservoir. *MS* and *OS* record features differ as follows.

- *MS* records are designed to model seasonal rule curve reservoir operations characterized by a designated top of conservation pool elevation that varies during the 12 months of the year. *OS* records are designed to simulate time series of either actual observed reservoir storage volumes or storage volumes previously determined with a simulation model for specified conditions of water resources, development, allocation, management, and use.
- Storage volumes are entered on a *MS* record for each of the 12 months of the year. These storage capacity limits are applied in each year of the simulation. Storage volumes are entered on *OS* records for each month of the simulation period-of-analysis. *OS* records are required for each year of the period-of-analysis.
- The storage capacity on a *MS* record is for an entire month from the beginning to the end of the month. Spills occur at the beginning of the month as necessary to prevent the storage capacity from being exceeded. *OS* records contain end-of-month storage volumes. End-of-month reservoir releases (spills) prevent the storage capacity from being exceeded.

CHAPTER 5 ORGANIZATION OF SIMULATION RESULTS

Chapter 5 describes the *SIM* simulation results recorded in the OUT, DSS, and SOU output files. These three files store the same time series simulation results output data but in different formats. The OUT file is designed to be read by the WRAP post-simulation program *TABLES*. The DSS output file is designed to be read with *HEC-DSSVue*. The SOU file can be viewed with any text editor such as WordPad or Word or transported to a MS Excel spreadsheet.

WRAP input and output files are referenced by their three-character filename extensions. The MSS, YRO, ZZZ, BES, BRS, and HRR files are special purpose *SIM* output files that are discussed in Chapter 6. Chapter 8 covers conditional reliability modeling (CRM) for which the OUT file is replaced with a CRM file containing sequences of the same variables in the same format as the OUT file. CRM results can also be recorded in a DSS file.

The WRAP daily modeling system is documented by the *Daily Manual*. *SIMD* stores its daily time series simulation results in its SUB and DSS files. *SIM* and *SIMD* store their monthly time series simulation results in their OUT file and DSS files. The time series variables are the same in all of these output files. About forty variables, which are defined later in the present Chapter 5, are recorded in the SUB file and DSS for each day of the *SIMD* daily simulation and in the OUT file and DSS file for each month of the simulation. Daily and monthly time series simulation results are stored as DSS records in the same DSS output file but separated with sub-monthly (daily) quantities in the SUB file and monthly quantities in the OUT file. This chapter focuses on monthly *SIM* (or monthly *SIMD*) simulation results. However, the daily *SIMD* simulation results discussed in the *Daily Manual* are organized in a similar manner.

Reliability and frequency analyses of simulation results, water budget analyses, time series plots, and various summary tables displaying simulation results are developed with the programs *TABLES* and *HEC-DSSVue*. Capabilities provided by *TABLES* are described in Chapter 7 of this *Reference Manual*. *TABLES* and *HEC-DSSVue* are covered in Chapters 4 and 5, respectively, of the *Users Manual* and are discussed throughout all of the WRAP manuals.

OUT, SOU, and DSS Output Files

The *SIM* simulation generates hydrologic period-of-analysis monthly sequences of up to about forty variables depending on options activated which are defined later in this chapter. Conventional applications of WRAP adopt the following two main strategies for storing the time series of simulation results. Each option provides key capabilities not provided by the other.

1. unformatted text file with filename extension OUT designed to be accessed by *TABLES*
2. binary file with filename extension DSS designed to be accessed by *HEC-DSSVue*

Simulation output records can be stored in an OUT file as either text or binary records. However, actual applications of WRAP have always used text records read by common text editors rather than binary records accessible only to specific software. DSS files are always in a special binary format read only by software with DSS capabilities. SOU files tabulate the output data in a columnar format that can be viewed with any text editor. *TABLES* includes flexible options for similar columnar tabulations and can also convert OUT file records to a DSS file.

OUT, SOU, and DSS files store the same simulation results output data but in different formats. Any or all of these three output files are activated with the optional files *OF* record described in Chapter 3 of the *Users Manual*, with the default being to employ only the OUT file.

A monthly *SIM* simulation generates the output variables defined later in this chapter for each month of the hydrologic period-of-analysis. A daily *SIMD* simulation generates daily versions of these same variables for each day of the hydrologic period-of-analysis. *SIMD* also aggregates daily quantities to monthly totals. The time series of simulation results output by *SIM* or *SIMD* are associated with either water rights, control points, or reservoir/hydropower projects. Simulation results are stored as water right output records, control point output records, and/or reservoir output records. Model users select the control points, water rights, and/or reservoir/hydropower projects for which the time series are to be recorded in the OUT, SOU, and DSS output files as described both later in this chapter and in the *Users Manual*.

As illustrated in Figure 2.2 of Chapter 2, the *SIM* simulation proceeds sequentially through each month of the hydrologic period-of-analysis. A water rights loop is embedded within the monthly time-step simulation loop. Within each month, water rights are simulated in priority order. Water right, control point, and reservoir/hydropower output records are written to the OUT file as the computations proceed by month and within each month by water right. Water right output records are created in the OUT file as each individual right is considered in the priority sequence. Control point and reservoir/hydropower output records are created each month at the completion of the water rights sequence prior to advancing to the next month. The same simulation results data are stored in memory and recorded in the SOU and DSS files at the completion of the entire simulation.

SIM Simulation Results Variables

SIM simulation results variables are defined on the following pages. The same quantities are organized in different formats in the OUT, DSS, and SOU files. The variables are time series of monthly quantities. All of the quantities are monthly volumes except evaporation-precipitation depths, reservoir surface elevations, and record counts. Flow rates are volumes (acre-feet) per month. Net evaporation-precipitation depths in feet and volumes in acre-feet also represent rates during each month. Reservoir storage volumes are volumes in acre-feet and surface elevations in feet occur at the end of each month. Although any consistent set of units can be adopted for a WRAP simulation, units of acre-feet for volume, acres for reservoir surface area, and feet for depth are typically employed.

Three-character labels are shown in parenthesis in the following definitions and in the tables presented later in the chapter. These labels serve as variable identifiers on DSS records in the DSS output file as described in Chapter 5 of the *Users Manual*. These identifiers are placed by *SIM* as headings for the columns in the SOU file as noted later in this chapter. These same labels with the numeral 2 appended serve as identifiers of the *TABLES* time series input records included in a *TABLES* input TIN file as explained in Chapter 7 of this manual and Chapter 4 of the *Users Manual*. The *TABLES* time series records cover all of the variables included in the *SIM* output OUT file and several other variables computed from the OUT file data. The *SIM* output variables are incorporated in various other types of tables created by *TABLES* as well as in time series tables as described in Chapter 7 of this *Reference Manual*.

Stream Flow at a Control Point

naturalized flows (NAT) – Naturalized flows recorded in the *SIM* output file are the flows read by *SIM* from *IN* records or *DSS* records or computed within *SIM* with the flow distribution methods described in Chapter 3. The *SIM* water rights simulation converts naturalized stream flows to regulated and unappropriated flows. With *FAD* option 1 activated, the naturalized flows in the *SIM* output file include computed *FA* record flow adjustments.

regulated flows (REG) – Regulated stream flows are the actual sequence of physical stream flows at a control point after all the water rights are allocated their water.

unappropriated flows (UNA) – Unappropriated flows are uncommitted flows still remaining after all the water rights are allocated their water. Unappropriated stream flows may be less than regulated flows due to instream flow requirements at the control point and requirements for passing flows through the control point for water rights located downstream.

Changes in Channel Loss in the Reach Downstream of a Control Point

channel loss (CLO) – Channel loss adjustments based on loss factors entered on *CP* records for a river reach below a control point as defined in Chapter 3 and the Appendix A Glossary. Channel losses are losses of return flows, hydropower releases, and other inflows.

channel loss credits (CLC) – Channel loss credits based on loss factors on *CP* records for the river reach below a control point. Channel loss credits are adjustments applied in determining effects on downstream flows resulting stream flow depletions occurring upstream.

Specific Components of Regulated Flow at a Control Point

return flows (RFR) – Return flows returning at this control point are the summation of return flows from all diversions that reenter the stream system at this control point. Reservoir releases for hydropower, releases from storage for downstream instream flow requirements, and water right type 4 inflows are also treated as return flows and included in this variable.

releases (URR) – This portion of the regulated flow consists of the summation of releases from reservoirs located at this control point and upstream control points that were made to meet water right requirements at other control points located downstream. The releases are from secondary reservoirs located upstream of diversion, hydropower, or instream flow rights.

control point inflows (CPI) – The 2CPI record data are the total monthly inflow to a control point excluding releases from secondary reservoirs located upstream of the control point for diversion or hydropower rights that are located downstream. Inflows to a control point are not included in the *OUT* file but rather are computed within *TABLES* by combining other variables from the *OUT* file. The 2CPI inflow is computed by adding the stream flow depletion (2DEP) at the control point to the regulated flow (2REG) less secondary reservoir releases (2URR). If there are no water rights at the control point or downstream control points that have secondary reservoirs located upstream of the control point, the 2CPI inflow represents the total actual inflow at the control point. The inflow includes stream inflows, diversion return flows returned to that control point, and hydropower releases returned to that control point. The inflows referenced in *TO* record fields 5 and 6 and *FS* record field 2 are conceptually the same but are computed at a point within the water right priority sequence. The 2CPI record contains the final values after considering all water rights.

Reservoir Storage and Net Evaporation Volumes for a Control Point, Right, or Reservoir

storage (STO) – End-of-month reservoir storage may be for an individual water right, reservoir, or control point. For a reservoir, the storage is the actual total volume of water stored in the reservoir at the end of the month. For a control point, it is the summation of storage for all reservoirs located at that same control point. For a water right, the level to which the individual right filled the reservoir is reported.

net evaporation-precipitation (EVA) – Reservoir net water surface evaporation less precipitation volume may be the cumulative total for an individual water right or for an individual reservoir. For a control point, the net evaporation-precipitation volume is the summation of final reservoir amounts for all reservoirs assigned to that same control point.

Water Right Quantities Reported by Right and Also Aggregated by Control Point

stream flow depletion (DEP) – As defined in Chapter 3 and the Glossary of Appendix A, the stream flow depletion is the amount of water appropriated by a water right to meet diversion requirements and maintain reservoir storage. The amount reported for a control point is the summation of stream flow depletions for all water rights assigned to the control point.

diversion target (TAR) – A diversion target is set for a water right in a series of steps governed by the *WR*, *UC*, *SO*, *TO*, *TS*, *FS*, *DI*, and other *SIM* input records. *SO* record field 9 specifies the intermediate or final target and shortage to be written to the OUT file. The diversion target amount reported for a control point is the summation for all water rights assigned to the control point. For an *IF* record right with *IFMETH* 3 or 4 options activating reservoir releases, the target variable is used to store the reservoir release target which is treated the same as a diversion target as described in Chapter 4. This diversion target variable is not applicable for an *IF* record right without reservoir storage (*IFMETH* options 1 and 2).

diversion shortage (SHT) – A diversion shortage for a given water right in a given month is the final diversion target less the actual diversion volume as constrained by water availability. The diversion shortage is associated with individual water rights. The amount reported for a control point is the summation of shortages for all water rights assigned to the control point. For an *IF* record right, the shortage is a failure to meet an *IFMETH* option 3 or 4 reservoir release target as described in Chapter 4.

diversion (DIV) – The actual diversion is not included in the *SIM* output file but is computed by *TABLES* as the target minus the shortage. For an *IF* record right with reservoir storage, the amount reported in the OUT file as the diversion variable is actually release from an *IFMETH* 3 or 4 reservoir as described in Chapter 4. The *TABLES* 2DIV and 2SHT records also create tables for hydroelectric energy. Water right output records include either diversions or hydropower targets and shortages. Control point output records include the summation of diversion targets or shortages but record zeros for hydropower.

instream flow target (IFT) – Instream flow targets are specified by *IF* input records and supporting input records as described in *Reference Manual* Chapter 4 and *Users Manual* Chapter 3. *SO* record field 9 specifies the intermediate or final target and shortage written to the OUT file for a given *IF* record right. Options for combining multiple instream flow *IF* records at the same control point include adopting the junior target, largest target, or smallest target. The

target adopted by the *IF* record right at its priority in the priority sequence is recorded in the instream flow right output record. The target recorded on the control point output record is the final target at the end of the priority sequence. An option allows the target developed for an *IF* record to be applied at multiple control points. The target will be on the OUT file output records of each of the multiple control points but on only one *IF* right output record.

instream flow target (TIF) – With only one *IF* record instream flow right at a control point the IFT and TIF targets are the same. With two or more instream flow rights located at the same control point, the TIF targets are targets for an individual IF record target prior to combining with targets for other *IF* record instream flow rights at the same control point.

instream flow shortage (IFS) – An instream flow shortage is the amount by which the monthly regulated flow volume (REG) falls below the instream flow target (IFT). Shortages are recorded in instream flow output records at the priorities of the right in the priority sequence. Control point output records include instream flow targets but do not include instream flow shortages. *TABLES* computes shortages for a control point as the difference between the target volume and regulated flow volume when the regulated flow is below the target.

instream flow target supplied (IFF) – The portion of the instream flow target that is supplied (IFF) is not recorded in the OUT file but rather is computed from the IFT, IFS, and REG quantities that are included in the OUT file. IFF can be associated with either water rights or control points. For water rights, IFF is computed as the target IFT minus the shortage IFS. For control points, IFF is computed as the target IFT minus regulated flow REG when REG is less than IFT, and IFF is zero otherwise.

Hydroelectric Energy Reported on Water Right Output Records

energy target (TAR) – Either diversion or hydroelectric energy, but not both, may be specified by a water right as the type parameter in *WR* input record field 6. A hydroelectric energy target or diversion target is set for a water right in accordance with *WR*, *UC*, *SO*, *TO*, *DI*, and other *SIM* input records. The target for each right is recorded on a water right output record. Aggregated target amounts are also recorded on control point output records for diversion rights but not for hydropower rights. Reservoir/hydropower output records also include the final accumulative hydroelectric energy target generated by the most junior water right connected to a reservoir. If only one hydropower right is associated with a reservoir, the energy target is the same on the water right output record and reservoir/hydropower output record. However, with multiple rights, the water right output record has cumulative targets and shortages for individual rights. Reservoir/hydropower output records have only the final accumulative hydroelectric energy target for the most junior water right at a reservoir.

energy shortage (SHT) – Depending on the water right type specified in *WR* record field 6, either an energy shortage or diversion shortage, but not both, may be recorded in the OUT file on a water right output record. The hydroelectric energy shortage is reported as a positive number. Secondary energy is reported as a negative quantity. Shortages represent shortfalls in meeting an energy target. Secondary energy is the amount greater than the target resulting from releases through turbines to meet other senior water right requirements. The cumulative energy shortage or secondary energy is associated with individual water rights. Reservoir/hydropower output records also include the final accumulative energy shortage or secondary energy generation by the most junior water right connected to a reservoir.

firm energy generated (DIV) – The amount of the energy target actually produced is not included in the water right output record but rather is computed by *TABLES* as the target minus the shortage. Firm energy generated equals target minus shortage. The *TABLES* 2DIV record creates tables of either diversions or hydroelectric energy in the same manner.

Additional Variables Recorded Only on Water Right Output Records

flow volumes and counts (FSV and FSC) – Flow switch *FS* record flow volumes and counts are recorded on *SIM* instream flow *IF* record right output records. The accumulated flow volume of the switch variable *FSV* is read by a *TABLES* 2FSV record. The count of the number of months of the simulation during which the monthly *FSV* volume falls within a specified range is read by a FSC record.

return flow (RFL) – The return flow volume for this particular water right is the portion of the diversion volume that is returned to the river system following *WR* record specifications.

secondary reservoir releases (ROR) – Total volume released from secondary reservoirs this month for this water right following *OR* input record multiple-reservoir system operating rules.

available stream flow (ASF) – The amount of stream flow available to a water right is computed as each right is considered in the water rights priority loop.

increase in available flow (XAV) – The increase in available stream flow to result from the *PX* record control point limit option described in the last section of Chapter 4. This variable is recorded only if this *PX* input record fields 4 and 5 option is activated.

Additional Variables Recorded on Reservoir/Hydropower Output Records

energy shortage (HPS) – Both shortages in firm energy and additional secondary energy are recorded as the same variable in the OUT file. The hydroelectric energy shortage is reported as a positive energy amount. Secondary energy is reported as a negative amount. Shortages represent shortfalls in meeting an energy target. Secondary energy is the amount greater than the target resulting from releases through the turbines for other senior water rights.

energy generated (HPE) – The actual energy generated represents the portion of the energy target that was supplied. Only the firm energy target, not secondary energy, is included. The hydroelectric energy recorded on the reservoir/hydropower output record is the accumulated total energy generated by the most junior hydropower right associated with the reservoir.

flow depletions (RID) – Stream flow depletions associated with a reservoir include all the water taken from stream flow to meet water right requirements at the reservoir.

reservoir inflows (2RIR) – Reservoir inflows from other reservoirs consist of releases from secondary reservoirs to meet water right requirements at this reservoir.

releases (RAH) – Releases from the reservoir that can be used to generate hydropower. The parameter *LAKESD* entered on the *WS* input records of other non-hydropower rights controls whether or not water supply releases from a reservoir can be passed through hydropower turbines. The default option is for hydropower to access water supply releases.

releases (RNA) – Releases from the reservoir that are not accessible to the turbines for use in generating hydropower as governed by the parameter *LAKESD* entered on the *WS* input record. Diversions for water rights flagged as lakeside do not pass through the turbines.

adjusted net evaporation-precipitation depth (EPD) – Evaporation-precipitation depths used to compute volumes are based on *EV* records but are subject to adjustments related to runoff from the reservoir site as specified by *JD* record field 10 and *CP* record fields 8 and 9.

net evaporation-precipitation depth (EVR) – These are the monthly net evaporation-precipitation depths read from the *EV* records prior to the adjustments reflected in the 2EPD variable.

water surface elevation (WSE) – End-of-month reservoir elevations are computed by *SIM* as a function of storage volume by linear interpolation of the *PV/PE* record storage-elevation table. The only use of water surface elevation in the *SIM* simulation is determination of head for hydropower. However, *PV/PE* records may be provided for any reservoir, with or without hydropower, to tabulate water surface elevations for general information.

reservoir storage capacity (RSC) – Reservoir storage capacities are set by *WS*, *MS*, and *OS* input records from the DAT file and recorded on reservoir/hydropower records in the OUT file.

reservoir storage drawdown (RSD) – Programs *HYD* and *TABLES* determine storage drawdowns or shortages (RSD) by subtracting storage volume (STO) from capacity (RSC) read from the *SIM* OUT file.

Water Right Variables Aggregated by Reservoir or by Control Point

The organization of the *SIM* simulation is outlined in Figure 2.2 of Chapter 2. Most of the water allocation computations are performed within the water rights loop which is embedded within the monthly time step loop. Each water right is considered in priority order in the water right computation sequence. A water right output record is written to the OUT file upon completion of the computations for that individual right. After all water rights have been considered, the control point and reservoir/hydropower output records are created for that month.

Each variable in the *SIM* OUT file is associated with a control point, water right, and/or reservoir/hydropower project. Some data in the simulation results are unique to either water right, control point, or reservoir/hydropower output records. Other data are repeated on two or three of the output record types. In the *SIM* input dataset, any number of water rights may be located at the same control point or be associated with the same reservoir. Any number of secondary reservoirs may be assigned to the same water right. Any number of reservoirs may be assigned the same control point. The aggregation of variable values computed for individual water rights to reservoirs and control points is additive for some variables and otherwise selected for other variables.

End-of-month storage volume and evaporation-precipitation volume are written to all three types of records. If one water right with one reservoir is located at a control point, reservoir storage will be identical on all three records. However, in general, the amounts may be different. With multiple rights at the same reservoir, the total cumulative evaporation-precipitation volume and end-of-period storage is recomputed as each right is considered in the water right priority sequence.

For a water right that refills and/or releases from reservoir storage, an end-of-month storage volume and net evaporation-precipitation volume are computed as the individual right is considered in its turn in the water right priority sequence. If other more junior rights share storage in this same reservoir, storage and evaporation-precipitation volumes are recomputed two or more times for the same reservoir. The storage and net evaporation volumes computed by *SIM* in the water right priority

loop and recorded in the OUT file on water right output records consist of the accumulative totals at the reservoir considering that water right and all junior water rights. Senior rights have not yet entered the simulation computations. The storage volume and net evaporation-precipitation volume recorded on the reservoir/hydropower output record are the final accumulative volumes determined for the most junior water right at the reservoir. The amounts recorded on control point output records are the summation of the final volumes for all reservoirs located at the control point.

Several hydropower rights with different targets and priorities may be located at the same reservoir. However, the energy target set for each right is the total energy target considering that right and all junior hydropower rights at the reservoir. The energy computations are repeated in the water rights loop with releases committed to more senior hydropower rights still available to generate energy. The hydroelectric energy generated by each *WR* record right is the cumulative total energy considering that right and all junior rights. The cumulative energy target and shortage associated with individual rights are recorded on water right output records. Energy recorded on the reservoir/hydropower output record are the final amount generated by the most junior hydropower right at the reservoir. Hydroelectric energy is not reported on control point records.

The diversion targets and diversion shortages recorded on a control point record are the summations for all the diversion rights assigned to the control point. The diversions and shortages on a water right output record are associated with a single *WR* input record. Any number of water rights may make diversions at the same control point. Diversion volumes for individual rights are simply added to obtain the total for the control point.

The instream flow *IF* record target and shortage recorded on a water right record are the quantities in effect in the priority sequence of the *IF* record right. The instream flow target on a control point output record is the final target at the end of the priority sequence.

Naturalized, regulated, and unappropriated stream flows, and channel loss adjustments are recorded only for control points. However, available stream flow for individual rights reported on water right output records are computed by *SIM* based on intermediate values of regulated and unappropriated flows at pertinent points in the water rights priority loop sequence. Stream flow adjustments for channel losses and loss credits are also computed for individual rights and summed to obtain control point totals.

Several of the variables associated with water rights may also be aggregated within *TABLES* by user-specified groups of water rights. The model-user defines the grouping of water rights by entering group identifiers on *WR* input records which are reproduced by *SIM* on water right output records. Volumes for individual rights are added within *TABLES* to obtain totals for the group. The group aggregation is performed within the *TABLES* table building process.

Organization of SIM Output OUT File

Program *TABLES* reads the *SIM* simulation results OUT output file and develops an array of user-specified tables and tabulations as outlined in Chapter 7. A model-user may occasionally read an OUT file directly to track problems or better understand the program. However, the OUT file is designed to efficiently store voluminous data in the order in which it is computed. *TABLES* converts the *SIM* output data to readily useable information.

The OUT file may be created in either text or binary format and is designed to be accessed by program *TABLES* in either format. The default text file version of the OUT file can be read directly with Microsoft Word or WordPad as well as read by *TABLES*. The binary unformatted machine language version of the OUT file activated by the parameter *OUTFILE* on the *JD* record is read only by *TABLES*. The advantages of the binary option are a reduction in the size of the OUT file and a reduction in computer execution time. Also, since simulation results are stored on the computer hard drive in the same form as computed by the processor, there is no loss in precision. The data in the text file version of the OUT file are stored with the number of digits to the right of decimal shown in Tables 5.3-5.5 presented later in this chapter, which results in decreasing precision for small numbers. The binary *SIM* output file has become essentially obsolete with the integration of DSS in the WRAP programs. The binary DSS files provide all of the advantages of the binary OUT file along with significant other advantages.

Not all editors read the OUT text file. All of the WRAP output files that are created as text files, except the OUT file, can be directly read with essentially any editor including either Microsoft NotePad or WordPad. The text version of the OUT file is written by *SIM* in a direct access format designed to be efficiently read by *TABLES*. The OUT file contains line breaks that are read fine by Microsoft WordPad and Word but are not recognized by NotePad.

The location of the variables in the OUT file output records are summarized in Table 5.1. Each variable is associated with a control point, water right, and/or reservoir/hydropower project as indicated in Table 5.1. The second column of Table 5.1 lists the *TABLES* time series input record identifiers that create tables, tabulations, or HEC-DSS records for each of the variables. These identifiers are shown in parenthesis in the preceding list of variables. The organization of the OUT file records is outlined in Tables 5.2, 5.3, 5.4, and 5.5. The beginning of the OUT file for the example in the *Fundamentals Manual* is replicated as Table 5.6 to illustrate the general format.

The OUT file begins with the five lines of information shown in Table 5.2. The one-line header is followed by three title records (*T1, T2, T3*) read from the *SIM* input file. The fifth line contains the five integers defined in Table 5.2. The simulation results are then written in monthly blocks of data. Within each month of simulation results, output records for user-specified water rights are written first, followed by selected control point output records, followed by the records for selected reservoir/hydropower projects. The monthly data associated with each specified water right, control point, or reservoir/hydropower project are listed in Tables 5.3, 5.4, and 5.5. These records are all optional. The model-user specifies in the *SIM* input file which of the three types of output records and which water rights, control points, and/or reservoirs to include, following procedures outlined in *Users Manual* Chapters 2 and 3.

The OUT file is designed to compactly store the voluminous output data in the order in which it is computed. Water right records are written in order of priority as each water right is considered in the computational loop. Control point output records are in the same order as the *CP* records in the input file. Likewise, reservoir/hydropower records are in the order that reservoirs are first read in the input file. Examination of the OUT file may be useful occasionally for tracking problems, but the format is not convenient for routinely interpreting simulation results. The *SOU* file is designed to be much easier for people to read than the OUT file but does not record the output data in the exact order that is computed like the OUT file.

Table 5.1
Summary of *SIM* Simulation Results Variables Read by *TABLES* from OUT File Output Records

Variables Recorded in <i>SIM</i> OUT File or Computed Therefrom	<i>TABLES</i> Time Series Input Record	Control Point Output Record (Table 5.3)	Water Right Output Record (Table 5.4)	Reservoir and Hydropower (Table 5.5)
naturalized stream flow	2NAT	CP field 9		
regulated stream flow	2REG	CP field 10		
unappropriated flow	2UNA	CP field 7		
channel loss	2CLO	CP field 12		
channel loss credit	2CLC	CP field 11		
return flow returned here	2RFR	CP field 8		
upstream reservoir release	2URR	CP field 13		
control point inflow	2CPI	field 10 – 13 + 6		
reservoir storage	2STO	CP field 5	WR/IF field 6	R/H field 5
evaporation-precip volume	2EVA	CP field 4	WR/IF field 5	R/H field 4
stream flow depletion	2DEP	CP field 6	WR/IF field 7	
diversion target	2TAR	CP field 3	WR/IF field 4	
diversion shortage	2SHT	CP field 2	WR/IF field 3	
diversion	2DIV	field 3 – field 2	field 4 – field 3	
hydroelectric energy target	2TAR		WR field 4	
energy shortage	2SHT		WR field 3	
firm energy produced	2DIV		field 4 – field 3	
instream flow target	2IFT	CP field 14	IF field 11	
instream flow target	2TIF		IF field 13	
instream flow shortage	2IFS	fields 10 –14	IF field 12	
instream flow target met	2IFF	fields 10 & 14	fields 11 – 12	
flow switch record volume	2FSV		IF field 13	
flow switch record count	2FSC		IF field 14	
return flow for water right	2RFL		WR field 13	
available stream flow	2ASF		WR/IF field 8	
increase in available flow	2XAV		WR field 14	
secondary reservoir release	2ROR		WR/IF field 9	
hydropower shortage	2HPS			R/H field 2
electric energy generated	2HPE			R/H field 3
stream flow depletions	2RID			R/H field 6
inflows from reservoirs	2RIR			R/H field 7
releases useable for power	2RAH			R/H field 8
releases not accessible	2RNA			R/H field 9
adjusted evap-precip depth	2EPD			R/H field 10
evaporation-precip depth	2EVR			R/H field 11
water surface elevation	2WSE			R/H field 12
reservoir storage capacity	2RSC			R/H field 13
reservoir drawdown volume	2RSD			field 13 – field 5

Note: The *TABLES* input TIN file records with identifiers tabulated in the second column create time series variables defined in the first column with either quantities read directly from the *SIM* output OUT file or computed from these quantities with simple arithmetic operations.

Table 5.2
Organization of Main SIM Output File

First Five Records of WRAP-SIM Output File

OUT File from WRAP-SIM (July 2018 Version)

TITLE1

TITLE2

TITLE3

YRST NYRS NCPTS NWROUT NREOUT CR1 CR2 CR4

Definition of Variables on Fifth Record

YRST – first year of simulation

NYRS – number of years in simulation

NCPTS – number of control points in SIM output file

NWROUT – number of water rights in SIM output file

NREOUT – number of reservoirs in SIM output file

CR1 – length of simulation period from CR record

CR2 – starting month from CR record

CR4 – multiplier factor for starting storage from CR record

Block of Records Repeated for Each Period (Month)

water rights output records (number of records = NWROUT)

control point output records (number of records = NCPTS)

reservoir/hydropower output records (number of records = NREOUT)

Total Number of Records in WRAP-SIM Output File

number of records = 5 + (12×NYRS) × (NWROUT + NCPTS + NREOUT)

Table 5.3
Water Right Output Record

Diversion/Storage Rights			TABLES TABLES		Instream Flow Rights	
Field	Variable	Format	Record	Record	Variable	Format
1	year	I4			IF	A2
2	month	I2			month	I4
3	diversion or energy shortage	F11.3	2SHT	2SHT	reservoir release shortage	F11.2
4	diversion or energy target	F11.3	2TAR	2TAR	required reservoir release	F11.2
5	evaporation-precip volume	F11.2	2EVA	2EVA	evaporation-precip volume	F11.2
6	end-of-period storage	F11.2	2STO	2STO	end-of-period storage	F11.2
7	stream flow depletion	F11.2	2DEP	2DEP	stream flow depletion	F11.2
8	available stream flow	F11.2	2ASF	2ASF	available stream flow	F11.2
9	releases from other reservoirs	F11.2	2ROR	2ROR	releases from other reservoirs	F11.2
10	water right identifier	A16			water right identifier	A16
11	group identifier	A8		2IFT	instream flow target	F11.2
12	group identifier	A8		2IFS	instream flow shortage	F11.2
13	return flow	F11.2	2RFL	2TIF	target and FSV volume	F11.2
14	increase in available flow	F10.2	2XAV	2FSC	flow switch count	I4

Table 5.4
Control Point Output Record

Field	Variable	Format	Columns	TABLES
1	control point identifier	A6	1-6	
2	diversion shortage	F11.3	7-17	2SHT
3	diversion target	F11.3	18-28	2TAR
4	reservoir evaporation-precipitation	F11.2	29-39	2EVA
5	end-of-period storage	F11.2	40-50	2STO
6	stream flow depletion	F11.2	51-61	2DEP
7	unappropriated stream flow	F11.2	62-72	2UNA
8	return flows returning here	F11.2	73-83	2RFR
9	naturalized stream flows	F11.2	84-94	2NAT
10	regulated stream flows	F11.2	95-105	2REG
11	channel loss credits	F8.0	106-113	2CLC
12	channel losses	F7.0	114-120	2CLO
13	upstream reservoir releases	F8.0	121-128	2URR
14	instream flow target	F8.1	129-136	2IFT

Table 5.5
Reservoir/Hydropower Project Output Record

Field	Variable	Format	Columns	TABLES
1	reservoir identifier	A6	1-6	
2	hydropower shortage (+) or secondary energy (-)	F11.3	7-17	2HPS
3	energy generated	F11.3	18-28	2HPE
4	reservoir net evaporation-precipitation vol	F11.2	29-39	2EVA
5	end-of-period reservoir storage volume	F11.2	40-50	2STO
6	inflows to reservoir from stream flow depletions	F11.2	51-61	2RID
7	inflows to reservoir from releases from other reservoirs	F11.2	62-72	2RIR
8	reservoir releases that are accessible to hydroelectric power turbines	F11.2	73-83	2RAH
9	reservoir releases that are not accessible to hydropower turbines	F11.2	84-94	2RNA
10	adjusted evaporation-precipitation depths	F11.4	95-105	2EPD
11	evaporation-precipitation depths	F11.4	106-116	2EVR
12	reservoir water surface elevation	F11.3	117-127	2WSE
13	reservoir storage capacity	F9.1	128-136	2RSC

Note: The format columns of the tables use Fortran format statement terminology, where data types include character (A for alphanumeric), integer (I), and real (F). A6 refers to a 6-character field reserved for a character variable such as a control point or reservoir identifier. I4 refers to a 4-digit field for an integer (no decimal) number. A real number in F11.2 format may contain up to eleven characters counting decimal point and digits, with two digits to the right of the decimal point.

Program *TABLES* provides an array of options for organizing, tabulating, analyzing, summarizing, and displaying the simulation results in a variety of formats. The data in the *SIM* OUT file are incorporated into various tables created by *TABLES* including standard time series tables as well as the other types of tables described in Chapter 7. The *TABLES* input records that build standard time series tables for each type of data shown in parenthesis in the preceding list of variable definitions and listed in the second column of Table 5.1, middle columns of Table 5.3, and last column of Tables 5.4 and 5.5. As noted in Chapter 7, the numeral 2 is included in the *TABLES* input record identifiers to signify monthly data from the OUT file.

Water Right Output Records

Water rights in WRAP may be defined by either a water right *WR* record or instream flow *IF* record in the *SIM* input DAT file. Likewise, water right output records in the *SIM* output OUT file may be for either *WR* or *IF* record rights. As shown in Table 5.3, the water right output record for an *IF* input record instream flow right is different than the record for a *WR* input record right.

Each record provides data for a water right for a given month. The records for all of the water rights are grouped together for a given month. The variables are stored in the format indicated by the following Fortran format statements.

WR record water rights: Format (I4, I2, 2F11.3, 5F11.2, A16, 2A8, F11.2, F10.2)
IF record instream flow rights: Format (A2, I4, 7F11.2, A16, 3F11.2, I4)

Each *WR* record water right output record contains: year and month, shortage and target, net evaporation-precipitation volume, end-of-period reservoir storage, stream flow depletion by the water right, stream flow available to the right before the stream flow depletion, all water that was released from secondary reservoirs to meet the diversion and/or refill storage, the three identifiers from the *WR* input record, return flows, and an available flow increase generated only in conjunction with a *PX* record option.

The actual diversion volume or hydroelectric production is computed within *TABLES* as the target less the shortage. Depending on the water right type specified in *WR* record field 6 in the input file, either an energy shortage, diversion shortage, or storage shortage, may be recorded in the OUT file on a water right output record. The same variable is used to report both energy shortages and secondary energy. The hydroelectric energy shortage is reported as a positive energy amount. Secondary energy is reported as a negative amount. Shortages represent shortfalls in meeting an energy target. Secondary energy is the amount greater than the target resulting from releases through the turbines to meet other senior water right requirements.

Instream flow rights may include releases from reservoir storage to meet the regulated flow target. The release from storage required to meet the instream flow requirement is recorded in field 4 in lieu of diversion target, and the shortage in supplying the reservoir release is recorded in field 3. Fields 13 and 14 are nonzero only if a flow switch *FS* record is connected to the *IF* input record.

The net evaporation-precipitation volume and end-of-period storage volume in fields 5 and 6 are the values determined prior to considering any other junior rights that are associated with the reservoir. The amounts written for the most junior right at the reservoir are the actual values that

occur for the reservoir. Any amounts recorded for senior rights at the reservoir are intermediate values only. The reservoir net evaporation minus precipitation volume is positive if evaporation rate exceeds precipitation and negative if precipitation is greater.

The stream flow depletion in field 7 represents the monthly stream flow volume that the water right appropriated to supply the diversion target, account for reservoir net evaporation-precipitation, and/or refill storage. In months with a negative net evaporation-precipitation depth, the stream flow depletion may be a negative number. In this case, the water right actually makes water available to the river system by catching precipitation that falls onto the reservoir surface.

Releases from other reservoirs in field 9 are from secondary reservoirs to meet the storage and diversion requirements of the right. Releases from the primary reservoir are not included.

Control Point Output Records

Control point records for all of the control points included in the *SIM* output OUT file are grouped together for a given month. The 136-character record contains 14 variables stored in the format indicated by the following Fortran format statement.

Format (A6, 2F11.3, 7F11.2, F8.0, F7.0, F8.0, F8.1)

As indicated in Table 5.4, each record begins with the control point identifier, sum of the shortages and diversion targets for all diversion rights, evaporation-precipitation and end-of-period storage for all reservoirs, and stream flow depletions for all rights located at the control point. The next four fields contain the unappropriated flow remaining at the control point after all stream flow depletions have been made, the sum of the return flow returned at the control point from the current and previous month, and the naturalized and regulated stream flow. Fields 11 and 12 contain adjustments applied for channel loss credits and channel losses. Field 13 has the portion of the regulated flow that originates as releases made from reservoirs located at this control point or upstream to meet water right requirements at control points located further downstream. The final and most junior instream flow target at this control point is recorded in the last field.

Reservoir/Hydropower Project Output Records

Each reservoir/hydropower output record provides data for a reservoir and/or hydroelectric power plant for a given month. All the reservoir/hydropower records are grouped together for a given period which is always a month in *SIM* but may be a sub-monthly time step in *SIMD*.

The variables include energy shortage at the reservoir project, energy produced at the reservoir project, evaporation-precipitation, end-of-period storage, stream flow depletions made available to the reservoir, releases from other reservoirs made available, releases from the reservoir through the outlet works, lakeside releases from the reservoir, net evaporation-precipitation depths with and without runoff adjustments, reservoir water surface elevation, year, and month. The 136 character record outlined in Table 5.5 contains 13 variables stored in the following format.

Format (A6, 2F11.3, 6F11.2, 2F11.4, F11.3, F9.1)

The hydroelectric energy produced at the reservoir in each month is calculated from the average water surface elevation of the reservoir, the tailwater elevation for the most junior hydropower right associated with the reservoir, and the total flow through the outlet works for all hydropower rights and other senior rights. Either a turbine flow capacity may be specified or the power produced may be computed assuming that the turbine capacity is unlimited. Hydropower shortages are calculated as the algebraic difference between energy target and the energy produced. Positive shortage values signify that insufficient water was released from the reservoir to produce the energy requirement of the most junior hydropower right at the reservoir. Negative shortages represent secondary energy that was produced by releases through the outlet works to meet senior water right diversion and storage requirements.

Stream flow depletions include amounts for diversions as well as depletions to refill storage and account for net evaporation less precipitation. Depletions for diversions are assumed to enter a primary reservoir and then are either diverted lakeside or released through the reservoir outlet works. The releases written to a reservoir output record include releases made both as a primary and as a secondary reservoir.

Organization of SIM Output SOU File

The *SIM* output SOU file is an ordinary text file read directly with any editor, but is not accessible with *TABLES*. Although the OUT file can also be read directly without *TABLES*, it is designed for efficient data management focused on connecting with *TABLES*. The purpose of the SOU file is to present simulation results in a convenient-to-read columnar format designed to be examined directly with Microsoft WordPad, NotePad, or other editor or to be transported to Microsoft Excel or other spreadsheet program without intervention with *TABLES*. Similar tabulations can be created by *TABLES* from the data read from the OUT file.

Table 5.7
Simulation Results Variables

Control Point Variables	Water Right Variables	Reservoir/Hydropower Variables
NAT naturalized stream flow	STO reservoir storage volume	STO reservoir storage volume
REG regulated stream flow	EVA evaporation-precip volume	EVA evaporation-precip volume
UNA unappropriated stream flow	DEP stream flow depletion	HPS shortage/secondary energy
CLC channel loss credits	TAR diversion or energy target	HPE energy generated
CLO channel losses	SHT diversion shortage	RID inflows from depletions
URR upstream reservoir releases	DIV diversion or energy amount	RIR inflows from releases
CPI control point inflows	ASF available stream flow	RAH releases accessible to hydro
STO reservoir storage volume	ROR secondary reservoir release	RNA releases not accessible
TAR diversion target	RFL return flow	EPD evaporation-precip depth
SHT diversion shortage	IFT instream flow target	WSE water surface elevation
EVA reservoir net evaporation	IFT instream flow shortage	RSC reservoir storage capacity
DEP stream flow depletions	IFF instream flow supplied	
	FSV IF right <i>FS</i> record flow	
	FSC IF right <i>FS</i> record count	
	XAV available increaser	

The SOU and DSS output files are activated with the *SIM* optional files *OF* input record described in Chapter 3 of the *Users Manual*. The SOU (filename extension SOU) output file consists of tables for either control points, water rights, and/or reservoirs, with the first two columns being the year and month and the remaining columns being each of the time series variables. Table headings in the SOU file include the identifiers shown in parenthesis in the previous variable definitions and in Table 5.7 below. The optional files *OF* input record allows selection of all the simulation results variables or a subset thereof to include in the SOU and/or DSS output files. The SOU file organization is illustrated by Table 5.8, which contains an abbreviated set of variables. Only the first 27 months of a much longer simulation hydrologic period-of-analysis are included in Table 5.8 for brevity.

Table 5.8
Beginning of SOU File for the *Fundamentals Manual* Example

Control point identifier: PK

YEAR	MT	NAT	REG	UNA	STO	TAR	SHT
1940	1	10094.00	66120.23	0.00	497885.97	13893.514	0.000
1940	2	10172.00	0.00	0.00	491928.12	15346.859	0.000
1940	3	836.00	0.00	0.00	468528.19	17850.770	0.000
1940	4	16772.00	0.00	0.00	461625.97	21081.352	0.000
1940	5	114403.00	0.00	0.00	548220.31	23909.152	0.000
1940	6	289797.00	239386.02	239386.02	570240.00	26687.953	0.000
1940	7	45691.00	3185.21	3185.21	570240.00	28896.881	0.000
1940	8	242432.00	206742.31	74320.56	570240.00	27139.242	0.000
1940	9	54126.00	93567.66	0.00	496344.56	24498.135	0.000
1940	10	3317.00	0.00	0.00	470936.38	21228.352	0.000
1940	11	79433.00	0.00	0.00	534165.50	18371.150	0.000
1940	12	49363.00	0.00	0.00	567853.44	15896.641	0.000
1941	1	9910.00	0.00	0.00	561699.88	13893.514	0.000
1941	2	75951.00	54675.66	54675.66	570240.00	15346.859	0.000
1941	3	64391.00	43619.38	43619.38	570240.00	17850.770	0.000
1941	4	201160.00	179899.16	179899.16	570240.00	21081.352	0.000
1941	5	1267722.00	1244269.75	1244269.75	570240.00	23909.152	0.000
1941	6	627107.00	599129.94	599129.94	570240.00	26687.953	0.000
1941	7	140733.00	103367.27	103367.27	570240.00	28896.881	0.000
1941	8	116128.00	83440.77	83440.77	570240.00	27139.242	0.000
1941	9	103454.00	71041.81	33471.57	570240.00	24498.135	0.000
1941	10	758197.00	740215.88	634342.75	570240.00	21228.352	0.000
1941	11	137798.00	114270.48	114270.48	570240.00	18371.150	0.000
1941	12	43317.00	24727.95	24727.95	570240.00	15896.641	0.000
1942	1	26025.00	12151.72	0.00	566622.56	13893.514	0.000
1942	2	13531.00	0.00	0.00	560748.06	15346.859	0.000
1942	3	14131.00	14162.09	0.00	536867.00	17850.770	0.000
1942	4	468326.00	419911.50	419911.50	570240.00	21081.352	0.000

Organization of SIM Output DSS File

The Hydrologic Engineering Center (HEC) Data Storage System (DSS) and the HEC-DSSVue Visual Utility Engine are described in Chapter 6 of the *WRAP Users Manual*. DSS files and HEC-DSSVue provide efficient capabilities for managing large datasets of time series data, including *SIM* simulation results and hydrology input datasets. DSS files are in a binary format accessible only by DSS software. DSS routines developed by the Hydrologic Engineering Center are incorporated in the *WRAP* programs allow creation of and access to DSS files.

The same *SIM* simulation results can be recorded in DSS and OUT output files. The mechanisms described in the next section for selecting water rights, control points, and reservoirs for inclusion in the simulation results output files are applicable in the same manner to DSS, OUT, CRM, SOU, and SUB output files. However, *OF* record options for selecting subsets of simulation results variables are applicable only to the DSS and SOU files. The *OF* input record allows selection of all of the variables listed in Table 5.7 or any subset thereof to be included in the DSS and SOU files. All variables, not subsets thereof, are included in the other output files.

Specification of Control Points, Water Rights, and Reservoirs to Include in Output Files

WRAP-SIM simulation results are written to the OUT, CRM, SOU, and DSS output files in the form of the following three sets of output records, which are repeated for each month.

1. water right output records for both *WR* and *IF* record water rights
2. control point output records
3. reservoir/hydropower project output records

Likewise, *SIMD* daily simulation results are recorded in the DSS and/or SUB output files as daily time series associated with water rights, control points, or reservoir/hydropower projects.

Simulation result tables developed with *TABLES* are based on data in the *SIM* OUT or *SIMD* SUB output file. In organizing *SIM* simulation results with *TABLES*, the term all control points, all water rights, or all reservoirs in *TABLES* refers to all those included in the *SIM* output OUT file. Most tables in *TABLES* also include options for selecting sets of individual rights, control points, or reservoirs from those in the *SIM* output file. Thus, in organizing *SIM* simulation results with *TABLES*, selection of water rights, control points, and/or reservoir/hydropower projects is controlled by *SIM* input parameters governing creation of the OUT file as well as by *TABLES* input parameters governing selection and organization of data read from the OUT file.

The variables included in the OUT, CRM, SOU, and DSS files created by *SIM* and the DSS and SUB files created by *SIMD* to store time series of simulation results are listed in Tables 5.1, 5.3, 5.4, 5.5, and 5.7. In organizing simulation results, features are included in *TABLES* input TIN file records for selecting particular variables to read from the OUT or CRM file inclusion in the tables created by *TABLES*. However, control of data recorded in the *SIM* output OUT file is limited to selection of control points, water rights, and reservoir/hydropower projects to include in the output. All of the variables listed in Tables 5.3, 5.4, and 5.5 are included in the OUT file for each selected control point, water right, and reservoir/hydropower project. The *OF* input record allows any subset of variables to be included in the DSS and SOU files for each of the selected control points, water rights, and reservoir/hydropower projects.

SIM output records may be provided for every water right, control point, and reservoir/hydropower project. However, simulation results can be massive. The size of the output files and computer execution time may be reduced by including only selected data of interest. The *SIM* input DAT file includes information specifying which water rights, control points, and reservoir/hydropower projects are to be included in the main output OUT (or CRM), DSS, and SOU files. The same water rights are also included in the optional HRR output file.

The *JD* record in the *SIM* input DAT file may specify that all or none of the control points and/or water rights be included in the OUT, CRM, SOU, and DSS output files. Output records may be specified for any number of water rights, water right groups, control points, and/or reservoirs listed on *WO*, *GO*, *CO*, and *RO* input records, respectively.

Water right and control point output records include the following variables in common: diversion shortage, diversion target, evaporation-precipitation volume, storage, and stream flow depletion. The values for these variables on the control point output record reflect the summation for all rights at that control point. If only one water right is assigned to a particular control point, the values for these variables will be the same on both the water right and control point output records. Other variables pertain to either a water right or a control point but not both.

Water right, control point, and reservoir/hydropower output records all contain reservoir storage and net evaporation-precipitation volumes. Storage is refilled in priority order by any number of water rights associated with the same reservoir. The reservoir storage and net evaporation-precipitation volumes on the water right record are those amounts associated with that particular water right.

Parameters OUTCP and OUTWR on the *JD* Record

The options listed in Table 5.9 are selected with parameters OUTCP and OUTWR entered in *JD* record fields 5 and 6. These options are used in combination with *WO*, *GO*, *CO*, and *RO* records to specify which water rights and control points to include in the output files. *SIM* input records are described in Chapter 3 of the *Users Manual*.

Table 5.9
Control Point and Water Right Output Options for OUT, CRM, SOU, and DSS Files

Parameter OUTCP for Specifying Control Point Output	
Default	Control point output is specified only by <i>CO</i> records.
1	All control points except artificial control points are included in output.
2	Only control points with <i>IN</i> records plus those listed on <i>CO</i> records.
3	Only artificial control points plus those listed on <i>CO</i> records.
4	All control points including artificial control points are included in output.
≥5	First OUTCP control points plus those control points listed on <i>CO</i> records.
Parameter OUTWR for Specifying Water Right Output	
default	Water right output is specified only by <i>WO</i> and <i>GO</i> records.
1	All <i>WR</i> and <i>IF</i> record rights except hydropower rights and artificial rights.
2	All <i>WR</i> and <i>IF</i> rights including hydropower but excluding artificial.
3	Only non-hydropower and non-artificial <i>WR</i> record rights.
4	Only instream flow (<i>IF</i> record) rights are included in output files.
5	Only hydroelectric power rights are included in output files.
6	Only artificial water rights are included in output files.
≥7	First OUTWR rights in input file plus those listed on <i>WO</i> and <i>GO</i> records.

Reservoir/Hydropower Project Output Records

Reservoir/hydropower project output records are called reservoir records for brevity. The *RO* record provides the only means to specify reservoir/hydropower output records to include in the OUT, CRM, SOU, and DSS output files. The options are all, none, all except artificial, or those reservoir/hydropower projects listed on *RO* records. Variables included on reservoir records are listed in Table 5.5. Storage and net evaporation-precipitation are recorded on control point and water rights records as well as on the reservoir records. Energy production and shortage are included on both water rights and reservoir records. In many typical applications, reservoir/hydropower records will not be included in the output file if all the information of interest is available on water right and/or control point output records.

Control Point Output Records

The following alternative methods are provided for specifying which control point output records to include in the simulation results in the OUT, DSS, SOU, and CRM files.

- Parameter OUTCP on the *JD* record allows selection of either the *none* or *all* options. If option 1 is selected in *JD* field 5, all control points except artificial control points will be output. If OUTCP is blank or zero and there is no *CO* record, no control point data is output.
- OUTCP option 2 in *JD* record field 6 specifies output of just those control points for which *INMETHOD* on the *CP* record is 0, 1, or 2. These are primary control points for which naturalized stream flows are entered on *IN* records rather than being synthesized.
- OUTCP entries of 3 or 4 allows control point output records to be written for only artificial control points or all control points including artificial.
- *JD* record field 5 also allows the first any number of control points greater than four in the input file to be selected. For example, entering the integer 125 results in output records for the first 125 control points in the order that the *CP* records are found in the *SIM* input file.
- Control points listed on the *CO* record are included in the output along with those that may be specified by the *JD* record. *CO* records may be used alone (blank field 5 on *JD* record) or in combination with the *JD* field 5 options.

Water Right Output Records

The following methods are provided for selecting the water rights output records to include in the *SIM* simulation results files. OUTWR in *JD* record field 6 allows selection of either no rights, all rights with or without artificial rights, all *WR* record rights excluding hydropower rights, all hydropower rights, or all instream flow rights. OUTWR also allows the first any number greater than 6 of water rights in the input file to be selected. For example, entering the integer 32 in *JD* record field 6 results in output records for the first 32 water rights in the order that the *WR* records are entered in the *SIM* input file.

WO records are used to list the 16-character water right identifiers found in field 12 of the *WR* records or field 11 of the *IF* records. All rights with the identifiers listed on the *WO* records are output in addition to any that may be specified by the *JD* record as noted above.

Group output *GO* records list the 8-character water right group identifier found in fields 13 or 14 of the *WR* record or fields 12 or 13 of the *IF* record. All rights with the identifiers listed on *GO* records are output as well as those listed on *WO* records or specified by the *JD* record. The *GO* record also includes an option to treat the water use type identifiers in *WR* record field 4 as water right group identifiers.

Water Right Identifiers

A water right *WR* or instream flow *IF* record may have a water right identifier with a length of up to 16 characters and two group identifiers not exceeding 8 characters each. The 16-character identifier is unique to each water right. If the same 16-character identifier is entered on more than one *WR* or *IF* record, this identifier is ignored on the second and subsequent records. Any number of rights may have the same 8-character group identifier. The purpose of the group identifiers is to associate multiple rights together as a group. Unless specifically referenced by other records, water rights are not required to have identifiers. Identifier fields on *WR* and *IF* records may be left blank. Any, all, or none of the identifier fields may be used for any right.

Two alternative sets of three water rights identifiers may be included in the last six fields of the *WR* records (fields 12, 13, 14 and alternate fields 15, 16, 17). Only one of the two sets is read in a single execution of *SIM*. Input variable *IDSET* in *JD* record field 12 specifies whether the first or second set of three identifiers on the *WR* records is adopted in a particular model run.

Water right identifiers are used within the *SIM* simulation in selecting output and to reference rights for the firm yield *FY*, target options *TO*, and backup right *BU* record features. Control point identifiers are used much more extensively in the model computations to assign locations to various system features and otherwise define the spatial connectivity of the system.

The water right identifier fields on the *WR*, *IF* and other records do not have to be right or left justified as long as the identifier stays within the specified field. The program automatically removes trailing blanks, thus internally treating the identifiers like they were right justified.

Water right identifiers serve to identify rights in input and output files and tables created by *TABLES*. *TABLES* also includes options to aggregate the data associated with all rights with the same group identifier. The diversion targets, shortages, diversions, stream flow depletions, reservoir storage contents, and evaporation-precipitation volumes included in the output records for all water rights with the same group identifier in fields 13 and 14 or alternate fields 16 and 17 of the *WR* records may be summed within *TABLES* to obtain a set of aggregated total values.

For grouping purposes, all water rights with the same identifier in either of the two group identifier fields (second or third identifiers with up to 8 characters) compose a group. The group identifiers serve different purposes as follows.

1. All rights with an identifier listed on the *WO* or *GO* record will be included in the simulation results output file. Thus, multiple rights may be selected for inclusion in the output by including the same group identifier on each pertinent *WR* record and once on a *GO* record.

2. Program *TABLES* can read a *SIM* output file and create tables for either individual rights or for the summation of values for all rights with the same group identifier. For example, a table of diversion shortages (or stream flow depletions, etc.) would show the total diversion shortage in each month for all rights with the same group identifier.
3. The identifiers also allow the model-user to simply label the rights for general information. Various naming schemes may be devised to use the set of identifiers to label and organize the rights by various categories.
4. The *GO* record includes an option to treat the water use type identifiers in *WR* record field 4 as water right group identifiers. Thus, entries on the *GO* record allow selected types of water use defined on the *UC* records to be automatically adopted as group identifiers.

Artificial Control Points, Water Rights, and Reservoirs

As discussed on page 164 of the preceding Chapter 4, designation of control points, water rights, and reservoirs as being "*artificial*" does not affect the *SIM* or *SIMD* simulation computations. The sole purpose of the designation of artificial is to exclude simulation results quantities associated with these control points, water rights, and reservoirs from the simulation results output OUT, CRM, SOU, SUB, and DSS files. Artificial control points, artificial water rights, and artificial reservoirs are treated differently than regular control points, water rights, and reservoirs only in regard to their inclusion or exclusion in the output files.

Any number of control points, *WR* record water rights, and reservoirs in a *SIM* input DAT file can be classified as artificial as described in Chapter 3 of the *Users Manual*. The ARTIF parameter on the *CO* and *WO* records allow control points and water rights to be classified as artificial. The *CO* record ARTIF parameter is the only way to designate a control point as artificial. All water rights and reservoirs located at an artificial control point are automatically designated by *SIM* as being artificial. Quantities for artificial control points, *WR* record water rights, and reservoirs are included in the *SIM* output files only if certain output options controlled by the *JD* record are activated.

Labeling control points, water rights, and reservoirs as artificial does not affect the *SIM* simulation computations or regular "non-artificial" simulation results. The simulation results quantities associated with artificial control points, water rights, and reservoirs are separated from quantities associated with regular control points, water rights, and reservoirs for purposes of recording output records in the OUT and CRM files read by *TABLES* and also in the SOU and DSS output files. As *SIM* writes control point, reservoir, and water right output records, those labeled artificial can be omitted or included as desired.

CHAPTER 6

AUXILIARY CAPABILITIES FOR ANALYZING SIMULATION RESULTS

The preceding Chapter 5 discusses the time series of *SIM* simulation results recorded in the OUT file for organization and analysis with *TABLES* and recorded in the DSS file for organization and analysis with *HEC-DSSVue*. Analyses performed within *TABLES* are presented in the following Chapter 7. Chapter 8 explains the short-term conditional reliability modeling (CRM) variation of the *SIM*, *TABLES*, and *HEC-DSSVue* modeling system.

Chapter 6 covers *SIM* simulation results stored in supplemental output files and auxiliary modeling and analyses capabilities. Chapter 6 begins with a brief discussion of auxiliary non-WRAP software that can be employed with WRAP followed by a summary overview of *SIM* output files. The chapter then focuses on the following features of the WRAP program *SIM*.

- Yield-reliability table in *SIM* output YRO file activated by firm yield *FY* record.
- Priority sequence flow availability table in *SIM* ZZZ file activated by *ZZ* record and time series and frequency tables created with *TABLES* 4ZZZ and 4ZZF records.
- End-of-simulation reservoir storage volumes recorded by *SIM* in BES file for use as beginning-of-simulation storage volumes as controlled by *JO* record parameter BES.
- Reservoir storage capacity and beginning-of-simulation storage contents recorded in the *SIM* output BRS file activated by parameter BRS on the *JO* record.

The chapter ends with a general overview discussion of WRAP capabilities and applications for long-term simulation, short-term CRM, input compilation, salinity tracking, and daily modeling.

Auxiliary Software

As discussed initially in Chapter 1 and noted throughout this manual, use of other readily available software along with the WRAP programs serves various purposes. Other non-WRAP programs are used along with the WRAP programs to develop input datasets and organize and display simulation results.

Programs for Viewing and Editing Text Files

Microsoft WordPad and NotePad are used to create WRAP input files and to read and edit input and output files. Tables created with *TABLES* and plots created with *HEC-DSSVue* are transported into Microsoft Word documents when preparing reports. *SIM*, *TABLES*, and *HEC-DSSVue* create output files in optional columnar formats for convenient transport to Microsoft Excel. *HEC-DSSVue* imports data from Microsoft Excel files.

Notepad++ is an enhanced text editor that is similar to Microsoft Notepad and WordPad but provides additional features which are useful in creating and editing WRAP input data files and viewing output files. Notepad++ Portable is a full-featured Notepad++ text editor packaged as a portable app for convenience in application. Notepad++ is available free-of-charge at:

<http://notepad-plus-plus.org>

http://portableapps.com/apps/development/notepadpp_portable

WRAP Display Tool for ArcGIS ArcMap

Geographic information system (GIS) software is useful in dealing with spatial aspects of compiling WRAP input data and displaying simulation results. The ArcGIS software system marketed by the Environmental Systems Research Institute is a particularly popular GIS. Use of ArcGIS to develop WRAP input datasets is noted in Chapters 1 and 3.

An ArcGIS tool for displaying *WRAP-SIM* simulation results is available from the TCEQ WAM website as an executable setup file along with its user's manual [11]. The *WRAP Display Tool* is applied as an ArcMap toolbar. Flow and storage frequencies, water supply reliabilities, and other percentage-based indices derived from *SIM* simulation results are displayed by range as color coded symbols on a map. Time series graphs of *SIM* output data can also be plotted. The tool includes features for customizing applications along with its standard *SIM* output file manipulation and display capabilities.

Hydrologic Engineering Center HEC-DSS and HEC-DSSVue

The HEC-DSS (Data Storage System) was developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE) for use with its own generalized hydrologic, hydraulic, and water management simulation models. The HEC-DSS is also used with other non-HEC modeling systems including WRAP. Multiple simulation models share the same graphics and data management software as well as a set of basic statistics and mathematics routines. HEC-DSS database management and graphics capabilities are designed particularly for sequential time series data such as *SIM* and *SIMD* simulation results and hydrology input data.

The HEC-DSS Visual Utility Engine (*HEC-DSSVue*) is a graphical user interface program for viewing, editing, and analyzing data in DSS files [9]. The public domain *HEC-DSSVue* software and documentation may be downloaded from the USACE Hydrologic Engineering Center website. <http://www.hec.usace.army.mil/>

DSS files store data in a binary format that is accessible only by *HEC-DSSVue* and programs such as the HEC simulation models and WRAP programs that incorporate DSS routines from the HEC-DSS library in the computer code. The WRAP Fortran programs are linked during compilation to DSS routines from a static library file provided by the Hydrologic Engineering Center that allows access to DSS files.

Application of HEC-DSS and *HEC-DSSVue* with the WRAP programs is covered in detail in Chapter 6 of the *WRAP Users Manual* and discussed throughout all of the WRAP manuals. The WRAP programs store the following types of time series data in DSS files.

- *SIM*, *SIMD*, *HYD*, and *DAY* time series input data that includes naturalized flows (*IN* records), daily flows (*DF* records) net evaporation-precipitation rates (*EV* records), water right target series (*TS* records), flow adjustments (*FA* and *RU* records), and hydrologic indices (*HI* records).
- Simulation results including all of the time series variables defined in Chapter 5.

DSS and the *HEC-DSSVue* component of DSS are employed with the WRAP programs *HYD* and *DAY* in developing simulation input datasets and with the WRAP programs *SIM*, *SIMD*, and *SALT* in managing, displaying, and analyzing simulation results.

Statistical Analysis Software (HEC-DSSVue, HEC-SSP, and IHA)

The WRAP program *TABLES* provides comprehensive, flexible capabilities described in Chapter 7 for performing reliability and frequency analyses of *SIM*, *SIMD*, and *SALT* simulation results. The WRAP programs *HYD* and *DAY* have statistical analysis routines covered in the *Hydrology* and *Daily Manuals*. Non-WRAP programs providing significant additional different capabilities as well as replicating some of the WRAP capabilities for statistical analyses of WRAP simulation input data and simulation results include *HEC-DSSVue*, *HEC-SSP*, and the Indicators of Alteration (IHA) software described below.

HEC-DSSVue, *HEC-SSP*, and IHA share the following characteristics. The public domain software is free-of-charge and conveniently available online along with user's manuals. The statistical analysis systems have been extensively employed in many applications throughout the United States and abroad. All three programs read both text and DSS files. All three programs have been applied to perform statistical analyses of *WRAP-SIM* simulation results.

HEC-DSSVue and HEC-SSP

The *HEC-DSSVue Data Storage System Visual Utility Engine* and *HEC-SSP Statistical Software Package* [9, 30] are available from the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (<http://www.hec.usace.army.mil/>).

Statistical analyses are included in the variety of *HEC-DSSVue* capabilities employed with WRAP. DSS and *HEC-DSSVue* are described in Chapter 6 of the *WRAP Users Manual*. Features for computing basic statistics, linear regression, cyclic analysis, duration analysis, and frequency analysis with both tabular and graphical presentation of results are accessed through the following menu path: Tools/Math Functions/Statistics.

TABLES and *HEC-DSSVue* provide similar frequency analyses capabilities that can be applied to stream flow, reservoir storage, and all of the other simulation results variables. Some basic frequency analysis capabilities are the same in both programs. Each program provides certain analysis options not provided by the other. Both create frequency tables. *HEC-DSSVue* also creates frequency plots. Examples comparing *TABLES*, *HEC-DSSVue*, and *HEC-SSP* statistical frequency analysis features are found in Chapter 9 of the *WRAP Daily Manual*.

The *HEC-SSP Statistical Software Package* [30] is comprised of the following components.

- A general frequency analysis component applies the log-Pearson type III, Pearson type III, log-normal, and normal probability distribution functions to perform frequency analyses for annual series of peak flows or other variables. The Weibull formula is also applied.
- A flood flow frequency component applies the log-Pearson type III probability distribution to annual series of peak stream flows following standard procedures outlined in Bulletin 17B and 17C [31, 32].
- A volume frequency analysis component is designed for analyzing daily stream flow or stage data. Annual series of minimum or maximum volumes each year during durations of one or more days are analyzed based on an input daily dataset.

- A duration analysis shows the percent-of-time that a variable exceeds specified values.
- A coincident frequency analysis develops an exceedance frequency relationship for a variable as a function of two other variables.
- A curve combination analysis component combines frequency curves from multiple sources into one frequency curve.

Many of the computational capabilities of *HEC-SSP* applicable to WRAP are also found in the WRAP program *TABLES*. *TABLES* provides capabilities for developing detailed frequency tables designed specifically for WRAP simulation results that are not included in *HEC-SSP*. *HEC-SSP* provides convenient features for plotting frequency analysis results. A primary advantage of *HEC-SSP* over *HEC-DSSVue* and *TABLES* is more detailed flood frequency analysis. The daily *SIMD* simulation model includes an option for creating an annual series of maximum daily flows designed for flood frequency analyses. Both *TABLES* and *HEC-DSSVue* include standard flood frequency analysis routines. An example of flood frequency analysis of *SIMD* simulation results is presented in Chapter 6 of the *Daily Manual*.

The WRAP programs, *HEC-DSSVue*, and *HEC-SSP* are convenient to apply in combination. All of the programs access DSS files. *SIMD* simulation results can be recorded directly in a DSS file or alternatively can be organized by *TABLES* time series records as either columns in a text file or DSS records in a DSS file for transport to *HEC-SSP*. Columns in a text file can be transported to *HEC-SSP*. However, DSS files provide a more convenient mechanism to transport WRAP simulation results to *HEC-SSP*.

Indicators of Hydrologic Alteration

The Indicators of Hydrologic Alteration (IHA) is a statistical software package available from the Nature Conservancy that is designed for performing ecologically-meaningful statistical analyses of daily stream flows [33, 34]. The software and user's manual can be downloaded from the Nature Conservancy website (www.nature.org, <http://www.conservationgateway.org>). The computer software is designed to support assessment of hydrologic impacts of human activities by analyzing changes in daily flow statistics over time. The statistical analyses may also be used to support development of environmental flow standards. IHA does not directly generate instream flow requirements, but rather provides statistical information to support instream flow studies.

The IHA software has a feature called *environmental flow components* in which each day is assigned one of five flow regime categories: extreme low flow, low flow, high flow pulses, small floods, and large floods. An algorithm parses the input hydrograph accordingly based on user defined parameters and then generates summary frequency statistics corresponding to each flow regime component.

The IHA software has been applied by many scientists in locations around the world. Most applications have consisted of statistical frequency and trend analyses of observed daily river flows. The same types of statistical analyses of flow characteristics can be applied to *WRAP-SIMD* naturalized and regulated daily flows.

SIM Output Files

SIM input and output files are explained in Chapter 2 of the *Users Manual*. *SIM* output files are also listed in Table 6.1 and described here in this chapter. The various types of *SIM* output files are referenced by their filename extensions which are tabulated in the first column of Table 6.1. The *SIM* simulation results recorded in the different output files are briefly summarized as follows.

Table 6.1
SIM Output Files

Filename Extension	File Activation	Contents of File	Reference Manual Chapter
MSS	automatic	trace, error, and warning messages	Chapter 9
OUT	default	main simulation results read by <i>TABLES</i>	Chapter 5
SOU	<i>OF</i> record	main simulation results table	Chapter 5
DSS	<i>OF</i> record	main simulation results read by <i>HEC-DSSVue</i>	Chapter 5
YRO	<i>FY</i> record	yield-reliability table including firm yield	Chapter 6
ZZZ	<i>ZZ</i> record	priority sequence flow availability table	Chapter 6
BES	<i>JO</i> record	beginning and ending storage	Chapter 6
BRS	<i>JO</i> record	beginning reservoir storage	Chapter 6
HRR	<i>JO</i> record	hydropower and reservoir system releases	Chapter 6
CRM	<i>CR</i> record	results for conditional reliability modeling	Chapter 8

The main *SIM* simulation results consists of time series of variables defined in Chapter 5 stored in either an OUT file or CRM file and also in DSS and SOU files as discussed in Chapter 5. *SIM* creates either an OUT or CRM file but not both. The OUT file stores the results of a conventional long-term *SIM* simulation. The CRM file stores the results of the multiple shorter simulations generated when *SIM* is executed in conditional reliability modeling (CRM) mode as explained in Chapter 8.

OUT, CRM, ZZZ, BRS, and HRR files contain *SIM* simulation results that can be read, reorganized, and analyzed using *TABLES*. These text files can also be read directly with popular editors such as Microsoft WordPad. All WRAP input and output files except DSS files can be examined using essentially any editor. The BES file is designed to be both written and read by *SIM*.

Alternatively, the OUT or CRM file can optionally be created in an unformatted binary format read only by *TABLES*. However, the default text file version of the OUT and CRM files have always been employed in actual practical applications. The DSS file is in a binary format read only with *HEC-DSSVue* or other DSS accessible software. The MSS, SOU, YRO, and BES files are designed to be read with any editor but are not read by *TABLES*.

The OUT, DSS, and SOU files provide the same simulation results in different formats. The CRM file is the conditional reliability version of the OUT file. With the exception of the either/or OUT/CRM file, any or all of the other files can be generated in the same execution of *SIM*.

Message (MSS) File

A message file is always automatically created by *SIM* and each of the other WRAP programs. The *SIM* message file has the filename extension MSS. Message files provide trace messages tracking the progress of model execution, error and warning messages, and various other miscellaneous information. *SIM* provides options described in Chapter 9 of this manual allowing the user to select various types of information to be included in the MSS file.

Main Simulation Results Output (OUT) File

Program *TABLES* reads the main *SIM* simulation results output file, which has the filename extension OUT, and develops an array of user-specified tables and tabulations. A model-user may occasionally read an OUT file directly to track problems or better understand the program. Unlike the SOU and DSS files which are populated at the end of the simulation with simulation results stored in computer memory, simulation results are written to the OUT as computed as shown in Figure 2.2 of Chapter 2. The OUT file is designed to efficiently store voluminous data in the order in which it is computed. *TABLES* converts the *SIM* output data to readily useable information. The preceding Chapter 5 focuses on the simulation results recorded by *SIM* in its OUT file. Chapter 7 covers the further organization and analysis of *SIM* simulation results with *TABLES*. Reading and manipulating *SIM* simulation results from the OUT file with program *HYD* in conjunction with developing *SIM* hydrology input datasets are discussed in the *Hydrology Manual*.

Alternative Main Simulation Results Output (SOU and DSS) Files

The OUT, SOU, and DSS files contain the same simulation results described in Chapter 5 but differ in the format in which the data are stored. The alternative *SIM* files are activated with the optional output files *OF* input record. The OUT and SOU files are text files that can be read by any editor. The OUT file is designed to be read by *TABLES*. The SOU file presents the simulation results in a columnar format which is convenient for viewing directly with popular editors such as WordPad or transporting to a spreadsheet program such as Excel. *TABLES* can not read SOU or DSS files but can create DSS files. DSS files are designed to be read by *HEC-DSSVue*.

Yield versus Reliability Output (YRO) File

As discussed later in this chapter, the firm yield *FY* record activates a routine to develop a yield-reliability table for a diversion, which is written to the YRO file (filename extension YRO). The firm or safe yield is the last entry in the table. *SIM* creates this yield-reliability table directly as the simulation is iteratively repeated multiple times. *TABLES* is not involved in any way with the YRO file table. However, *TABLES* creates other reliability tables for fixed targets from the results of a single simulation that are discussed in the Chapter 7. Simulation results are normally not recorded in an OUT file if an YRO file is created, but the *FY* record does provide an option allowing the results from the last of the multiple simulations to be recorded in the OUT file.

Priority Sequence Stream Flow Availability (ZZZ) File

Simulation results stored in the ZZZ file activated by the ZZ record are also discussed later in this chapter. Regulated flows, available flows, and upstream reservoir releases at specified control

points are tabulated in a ZZZ file after each individual water right is simulated in the priority loop. The SIM output ZZZ file table may be read directly with any editor. The TABLES 2ZZZ and 2ZZF records activate TABLES routines for reading a ZZZ file and organizing the simulation results in optional time series formats or developing frequency tables.

Beginning-Ending Storage (BES) File

End-of-simulation reservoir storage contents may be saved for subsequent use as beginning-of-simulation reservoir storage. Beginning-ending storage (BES) options are described later in this chapter. A BES file may be both created and read by SIM. Program TABLES does not deal in any way with BES files.

Beginning Reservoir Storage (BRS) File

The optional BRS file is a table listing all reservoirs with the following data: reservoir identifier, control point location, storage capacity, and beginning-of-simulation storage content. Program SALT described in the salinity Manual and the TABLES CRM routine described in Chapter 8 of this manual contain options to read beginning-of-simulation storage from a BRS file. The BRS file may also be useful for general information.

Hydropower and Reservoir Release (HRR) File

The HRR file is used primarily for comparing releases from individual reservoirs of a multiple-reservoir system operated for the same water right. Simulation results in the OUT file (or SOU or DSS files) include data related to reservoirs and hydropower. However, multiple-reservoir system secondary reservoir releases, not found in the OUT file, are recorded in the optional hydropower and multiple-reservoir system release HRR file. Hydroelectric power generation is included in the HRR as well as OUT files. Tables created by TABLES as specified by a 4HRR input record organize these data into a more convenient-to-read tabular format.

The HRR file lists releases from primary and secondary reservoirs for each month of the simulation for each water right selected for output. The release from a primary reservoir is simply the diversion supplied by the water right, which is also recorded in the OUT file. For multiple-reservoir systems, the HRR file also provides a tabulation of the releases from each of the individual secondary reservoirs associated with a water right. Unlike the HRR file, the OUT file records only the aggregated total release from all of the secondary reservoirs. The HRR file also contains the hydroelectric energy target and amount of energy generated, which are also found in the OUT file.

Conditional Reliability Modeling (CRM) File

Conditional reliability modeling (CRM) is covered in Chapter 8. The CRM file is activated by a CR record. The CRM file is the conditional reliability modeling version of the OUT file. SIM creates either an OUT file or CRM file, but not both. The same simulation result variables are contained in either the OUT or CRM file. However, the CRM file reflects the subdivision of the hydrologic period-of-analysis into multiple sequences associated with short-term CRM modeling conditioned on preceding reservoir storage contents.

Yield Versus Reliability Relationships Including Firm and Safe Yields

The annual water supply diversion target or hydroelectric energy generation target is entered in the *SIM* water right *WR* record field 3 as the input variable *AMT*. Modeling applications may require computing volume and period reliabilities (defined by Equations 7.1 and 7.2 in Chapter 7) for a range of different values for *AMT*. Firm or safe yields may also be of interest. The reliabilities associated with various annual yields, representing the variable *AMT*, which include a computed firm or safe yield, may be developed by running *SIM* multiple times, manually changing the *AMT* entry in *WR* record field 3 for each run. An option activated by the *FY* record automates this procedure. In a single *SIM* execution, multiple simulations are repeated with the annual target amount *AMT* being systematically changed. The resulting yield-reliability table is written as a *SIM* output file with the filename extension YRO.

The *FY* record and resulting YRO file table are also applicable to the annual instream flow target *AMT* in *IF* record field 3. For purposes of the *FY* record (YRO file) computations that iteratively vary *AMT*, the shortages in meeting the monthly instream flow targets are defined as follows. If the flow regulated for exceeds the target, the shortage is zero. If the regulated flow is less than the target, the shortage is the target less the regulated flow. Regulated flow refers here to the regulated flow in the current month at the control point of the *IF* record water right at the priority of the right in the priority-based simulation computations.

The algorithm outlined here consists of replacing the annual target amount *AMT* of *WR* or *IF* record field 3. Typical units for *AMT* are acre-feet/year for water supply diversion and instream flow targets and megawatt-hours/year for hydroelectric energy generation targets.

Concept of Firm versus Safe Yields

The "*firm yield*" of a reservoir or multiple-reservoir system generally refers to the simulated maximum annual diversion volume that can be supplied without incurring a shortage during a hydrologic period-of-analysis simulation. The terms "*safe yield*" or "*dependable yield*" have been commonly used in water management practice either interchangeably with or at least similarly to "*firm yield*". The terms "*firm yield*" and "*safe yield*" are defined in the following paragraphs with specific differences from the perspective of the *SIM* routine activated by the *FY* record that creates a yield versus reliability table in a file with filename extension YRO.

Firm yield is defined as the maximum annual diversion volume (variable *AMT* in *WR* record field 3) that can be supplied in a *SIM* simulation with no shortage. The firm yield is the largest annual diversion volume for a particular water right that has a volume reliability of 100.0 percent. This value for *AMT* results in the one or more reservoirs supplying a water right just emptying without incurring a shortage. Firm yield computations can also be applied to run-of-river diversion rights with no reservoir storage. However, essentially no river reaches in Texas, or many other places, provide a non-zero or non-negligible firm yield. Water supply diversions supplied by reservoir storage may also have computed firm yields of zero due to evaporation.

Firm yield is computed based on the premise of supplying full demand targets as long as water is available. Safe yield is an expanded version of firm yield that allows the iterative simulations to incorporate water supply/demand management criteria other than simply supplying

demands as long as water is available. The *FY* record options include the following two strategies for defining safe yield criteria.

1. Allow a specified level of shortages, expressed as a fraction of demand, to occur during a specified number of consecutive months without declaring a water supply failure.
2. Requiring that the reservoir storage contents are not depleted below a specified level of reserve storage volume representing a specified number of months of water supply.

Firm yield is computed by the iteration algorithm controlled by the *FY* record parameters FYIN(2), FYIN(3), FYIN(4), and FYIN(5) defined in Table 6.2. Safe yield is an expanded version of firm yield defined by the optional additional *FY* record parameters FYIN(1), FYC(1), FYC(2), FYC(3), and FYIN(6) also defined in Table 6.2.

Table 6.2
Input Parameters on the *FY* Record

Parameter	Options	Description
<u>Specification of One or Multiple Water Rights to Share the Water Supply Yield</u>		
FYWRID		Water right identifier from water right <i>WR</i> record field 12.
FYGROUP		Water right group identifier corresponding to <i>WR</i> fields 13 or 14.
MFY		Two alternative options for allocating diversion among multiple rights.
	1	Proportional to annual diversions amounts <i>AMT</i> in <i>WR</i> field 3.
	2	Based on priorities in <i>WR</i> record field 5.
<u>Specification of Yield Increments for the Iterative Simulation Algorithm</u>		
FYIN(2)		Initial value for the annual diversion or hydropower target amount.
FYIN(3)		Incremental decrease in annual target for first level of decreases.
FYIN(4)		Incremental decrease in annual target for second level of decreases.
FYIN(5)		Incremental decrease in annual target for third level of decreases. A non-zero FYIN(5) also activates a fourth level of decreases.
<u>Additional Optional Parameters for Defining Safe Yield Quantities</u>		
FYC(1)	0, -, +	FYC(1) controls the manner in which target fraction FYIN(1) is used.
FYC(2)	blank, 0	Reservoir storage water supply reserve option is not employed.
	1, -1	Storage reserve is based on diversions during FYC(3) months.
	2, -2	Storage reserve is based on diversions and net reservoir evaporation.
	3, -3	Storage reserve based on net storage drawdown over FYC(3) months.
	4, -4	Storage reserve is specified as FYIN(6). FYC(3) is not relevant.
FYC(3)		Number of months for computing reserve for FYC(2) = 1, 2, 3
FYIN(1)		Fraction of target supplied which is employed as specified by FYC(1).
FYIN(6)		Water supply storage reserve specified by FYC(2) option 4.
<u>Optional Recording of Results of Final Simulation in the <i>SIM</i> output OUT File</u>		
SIM3	blank, 0	OUT file is not employed. Only MSS and YRO output files are used.
	non-zero	The results of the final simulation is recorded in the OUT file.

Automated Iterative SIM Simulation Procedure

Input parameters entered on the *FY* record are defined below in Table 6.2 and discussed in the following paragraphs. These *FY* record variables are explained further in Chapter 3 of the *Users Manual*. *FYIN*(1,2,3,4,5,6) are real numbers. *FYC*(1,2,3), *MFY*, and *SIM3* are integers.

An annual water supply diversion amount or hydroelectric energy generation amount (input variable *AMT*) is entered in field 3 of each of the water right *WR* records. Without activation of the *FY* record feature, *AMT* is the annual diversion or hydroelectric energy target which is distributed over the 12 months of the year with water use coefficients from *UC* records and perhaps otherwise adjusted by options on other input records. The *FY* record routine replaces the value for *AMT* read from *WR* record field 3 with a hypothetical annual yield volume which is changed in each of the repetitive simulations controlled by the *FY* record specifications. *AMT* is the only input variable changed. The simulation is simply repeated with different values for *AMT*. Reliability metrics are computed from the results of each of the simulations with the different values for the annual yield *AMT*. With a yield-reliability analysis performed for a single water right (meaning a single *WR* record), the annual yield is the *AMT* for that water right. If the yield-reliability analysis is performed for multiple *WR* record water rights, the annual yield volume in the YRO table is the summation of the *AMT*s for all of the specified water rights.

The diversion or hydropower yield may be associated with a single water right or a set of any number of water rights. If associated with multiple water rights, two options are available for allocating the annual yield amount between rights.

1. With the first option (*MFY*=1 on *FY* record), the yield is allocated between rights in proportion to target amounts entered in field 3 of the water right *WR* records. Thus, the total yield is multiplied by fractions set by the model-user to determine the proportion of the total yield assigned to each water right as illustrated by the example in Table 6.3.
2. The second option (*MFY*=2 on *FY* record) is based on the priorities from field 5 of the *WR* records. The yield is assigned to the most senior priority right up to the target amount specified in field 3 of its *WR* record. Any yield remaining is assigned to the next most senior priority right up to its target amount, and so forth. Upon reaching the most junior right, the remaining portion of the yield, if any, is assigned to the most junior right regardless of its *WR* record target amount.

The yield-reliability table reproduced as Table 6.3 is provided to illustrate the automated yield-reliability table creation procedure based on searching for the firm yield. Safe yield options are not activated. Another example is presented later that deals with safe firm. The YRO file table presented as Table 6.3 is created with the following entries on a *FY* record:

```
FYIN(1) = 0.92
FYIN(2) = 200,000 acre-feet/year
FYIN(3) = 10,000 acre-feet/year
FYIN(4) = 1,000 acre-feet/year
FYIN(5) = 100 acre-feet/year
Either FYWRID = Jones Reservoir and/or FYGROUP = yield
MFY = 1
```

The yield-reliability table begins with a list of the water rights for which the target amounts are adjusted. *FYWRID* and *FYGROUP* from the *FY* record connect with the water right identifier and water right group identifiers on *WR* records. The water right identifier and two group identifiers are listed for each right on the top of the yield-reliability table. Using MFY option 1 outlined above, the annual target is divided between the rights by the percentages shown, which are computed based on directly proportioning the annual target volumes (AMTs) from their *WR* records. Thus, the first right in the example, which represents a municipal diversion from Jones Reservoir, accounts for 38.78% of the annual target shown in the table.

Table 6.3
Example *SIM* Yield-Reliability Output File in Firm Yield Format

Yield Versus Reliability Table for the Following Water Right(s):

```

38.782 percent: Jones Reservoir   municipa  yield
52.148 percent: Jones Reservoir   industri yield
9.070 percent: Jones Reservoir    irrigati  yield
  
```

If more than one right, the target amount is distributed using the percentages shown above. The total number of periods is 696. The period reliability is the percentage of the periods for which at least 92.0 percent (FY record field 2; default=100%) of the target is supplied.

The table ends with the maximum target (firm yield) that results in a mean annual shortage of less than 0.05 units if such a firm yield exists.

Iteration	Level	Annual Target	Mean Shortage	Mean Actual	Volume Reliability (%)	Periods Without Shortage	Period Reliability (%)
1	0	200000.0	16025.7	183974.3	91.99	630	90.52
2	1	190000.0	13327.9	176672.1	92.99	639	91.81
3	1	180000.0	10741.8	169258.2	94.03	646	92.82
4	1	170000.0	8321.3	161678.7	95.11	656	94.25
5	1	160000.0	6077.6	153922.4	96.20	664	95.40
6	1	150000.0	4533.4	145466.6	96.98	672	96.55
7	1	140000.0	3274.3	136725.7	97.66	677	97.27
8	1	130000.0	1828.7	128171.3	98.59	683	98.13
9	1	120000.0	432.1	119567.9	99.64	692	99.43
10	1	110000.0	0.00	110000.0	100.00	696	100.00

11	2	119000.0	284.9	118715.1	99.76	694	99.71
12	2	118000.0	162.5	117837.5	99.86	695	99.86
13	2	117000.0	40.5	116959.5	99.97	695	99.86
14	2	116000.0	0.00	116000.0	100.00	696	100.00

15	3	116900.0	25.6	116874.4	99.98	695	99.86
16	3	116800.0	10.7	116789.3	99.99	696	100.00
17	3	116700.0	0.00	116700.0	100.00	696	100.00

18	4	116790.0	9.24	116780.8	99.99	696	100.00
19	4	116780.0	7.76	116772.2	99.99	696	100.00
20	4	116770.0	6.27	116763.7	99.99	696	100.00
21	4	116760.0	4.78	116755.2	100.00	696	100.00
22	4	116750.0	3.29	116746.7	100.00	696	100.00
23	4	116740.0	1.80	116738.2	100.00	696	100.00
24	4	116730.0	0.32	116729.7	100.00	696	100.00
25	4	116720.0	0.00	116720.0	100.00	696	100.00

Each line in the YRO file table represents the results of a *SIM* simulation. The annual target amount *AMT* is the only input variable that changes between simulations. No other features of *WRAP-SIM* are affected. All other features remain in effect.

FYIN(1) entered in *FY* record field 2 is the fraction of the monthly target that must be met in order for the routine to not declare that month a failure in the computation of period reliability. *FYIN(1)* might be set at 0.92 for an analysis based on the premise that a 8% reduction in water use through demand management measures is acceptable during dry periods. The *FYIN(1)* default is 1.0, meaning the entire target must be met in order to not declare a failure in meeting the target that month. With the default (blank) *FYC(1)* option, *FYIN(1)* affects only the number of periods without shortage and corresponding period reliability shown in the last two columns of Table 6.3. It is not used in the volume reliability computations (columns 3, 4, 5).

The firm yield criterion for stopping the iterative routine is based on reaching a total shortage of essentially zero, defined as less than 0.05 unit of the units being used (for example 0.05 acre-feet/year). If *FYIN(1)* is not the default 1.0, the 100% period reliability yield may be larger than the 100% volume reliability yield. Both are shown in the yield-reliability table. In the example with *FYIN(1)*=0.92, the volume reliability firm yield is 116,720 acre-feet/year and the period reliability firm yield is 116,800 acre-feet/year.

The iterative simulations are organized as follows.

1. The total annual target amount *AMT* equals *FYIN(2)* (=200,000 ac-ft/yr) from the *FY* record for the first simulation. With *MFY* option 1, *AMT* for the initial and all subsequent iterations is distributed to multiple water rights in proportion to *WR* record field 3 *AMTs*, with resulting percentages listed at the top of the table, to determine the individual *AMT* for each of the rights. The following steps are identical regardless of which of the two *MFY* options is activated in *FY* field 9 for distributing the target amount between water rights.
2. The total annual target amount *AMT* is decreased by *FYIN(3)* for each subsequent level 1 iteration until either no shortages occur or the target is finally decreased to zero or less.
3. If both *FYIN(4)* and *FYIN(5)* are zero, the computations stop. If *FYIN(4)* is not zero, the computations proceed to level 2. In the example, since *FYIN(4)* of 1,000 ac-ft has been entered on the *FY* record, the computations proceed to level 2.
4. For level 2, the initial target amount *AMT* is set equal to the next-to-last target amount from the level 1 iterations (120,000 ac-ft). *AMT* is decreased by *FYIN(4)* (1,000 ac-ft) for each level 2 iteration until either no shortages occur or the target *AMT* reaches zero.
5. If *FYIN(5)* is zero, the computations stop without proceeding to levels 3 and 4. Otherwise, level 3 iterations are performed using *FYIN(5)* as the incremental decrease in *AMT*. For the example, *FYIN(5)* is 100 ac-ft.
6. If *FYIN(5)* is not zero, upon completion of the level 3 iterations, an extra level 4 set of iterations is performed with the incremental decrease set at 10 percent of *FYIN(5)*.

The *FY* record computations are performed for only one annual diversion or hydropower amount. A single annual target amount is adjusted during the iterative routine. However, this

amount may be shared by any number of water rights (*WR* records). The water right identifier in *FY* record field 7 is matched with the identifiers entered in water right *WR* record field 11. The water right group identifier in *FY* record field 8 is matched with the identifiers entered in water right *WR* record fields 12 and 13. The annual amount is divided between multiple rights based on the choice of two optional method specified by *MFY* in *FY* record field 9. For those rights designated by *FYWRID* and *FYGROUP* on the *WR* record, this is the only use made of the amounts entered in field 3 of their *WR* records. If only one right is designated by the *FY* record, an amount entered in field 3 of its *WR* record is not used for anything in the computations.

Optional Safe Yield Criteria

The formats of YRO tables based on firm yield versus safe yield criteria are illustrated by Tables 6.3 and 6.5. The first seven columns of the YRO table are common to both formats. Three additional columns are added if safe yield quantities are computed. Also, the number of lines in the YRO table vary depending on whether the iterative simulations are designed to search for the firm yield or to search for the safe yield. The YRO file table format illustrated by Table 6.5 is created if and only if a non-zero value is specified on the *FY* record for either *FYC(1)* and/or *FYC(2)*. Otherwise the format illustrated by Table 6.3 is adopted.

Non-zero entries for the input variables *FYC(1)* and/or *FYC(2)* result in three additional columns being added to the YRO table with the following safe yield quantities:

- maximum number of consecutive months during the simulation with shortages exceeding $[1.0 - \text{FYIN}(1)]$
- storage reserve volume computed for the *FYC(3)*-month period preceding the minimum storage
- the minimum storage contents occurring during the simulation

Either negative or positive entries for *FYC(1)* and/or *FYC(2)* result in these quantities being computed and tabulated in the last three columns of the YRO table. Positive values for *FYC(1)* and/or *FYC(2)* also activate simulation repetition criteria switching to a iterative search for the safe rather than firm yield.

The *FY* record fields for the parameters *FYC(1)* and *FYC(2)* defined in Table 6.2 are left blank in the example of Table 6.3. Thus, the optional safe yield features are not activated in the previous example. The *FY* record options activate two different strategies for defining safe yield and supply failure criteria which can be applied either in combination or individually.

1. *FYC(1)* controls a scheme for defining safe yield that allows a specified level of shortages defined by *FYIN(1)* to occur during each of *FYC(1)* consecutive months. Safe yield is the maximum annual target that can be supplied with both (1) no monthly shortages exceeding $[1.0 - \text{FYIN}(1)]$ of the target and (2) the maximum number of consecutive months with non-zero shortages not exceeding *FYC(1)* months.
2. *FYC(2)* controls a scheme that defines safe yield based on a requirement that reservoir storage contents not be depleted below a reserve storage volume representing *FYC(3)* months of water supply. Safe yield is the maximum annual target that can be supplied without the reservoir storage volume dropping below the computed storage reserve.

With positive values entered on the FY record for both *FYC(1)* and *FYC(2)*, safe yield is defined as the maximum annual target that satisfies both the *FYC(1)* and *FYC(2)* criteria.

Regardless of whether *FYC(1)* is zero, negative, or positive, the period reliability tabulated in the YRO table is computed as $R = (n/N)(100\%)$ [Equation 7.2] where n is number of months for which at least *FYIN(1)* of the monthly target is supplied and N is the number of months in the simulation. A positive *FYC(1)* activates safe yield computations with *FYC(1)* being the limit on consecutive months of shortage. Shortages of less than $[1.0 - \text{FYIN}(1)]$ target can occur in not to exceed *FYC(1)* consecutive months without violating the safe yield criterion.

Optional Safe Yield Storage Reserve

An example presented in the *Fundamentals Manual* is referenced and expanded in various chapters of the other manuals. The *Fundamentals Manual* example includes application of the *FY* record, without the safe yield features activated, to compute the firm yield. This example is modified in the following discussion to compute safe yield. The input data files presented in the *Fundamentals Manual* remain unchanged except for the additional entries for the parameters on the *FY* record needed to convert the analysis from firm yield to safe yield. The *FYC(2)* reservoir storage reserve criteria are applied in the following discussion, but the *FYC(1)* allowable diversion shortage criteria described on the preceding page are not applied.

The example presented in the *Fundamentals Manual* includes computing a firm yield of 322,800 acre-feet/year for water right WR-24 which consists of a municipal water supply diversion at control point HEMP supplied by releases from reservoirs Possum Kingdom (PK), Belton (Belton), George (Georgetown), and Granger (Grang), which have water supply storage capacities of 570,240 acre-feet, 457,600 acre-feet, 37,100 acre-feet, and 65,500 acre-feet, respectively. Draw-downs in these four reservoirs are refilled by water rights WR-25, WR-26, WR-27, and WR-28. The *WR* and supporting records for these water rights in the DAT file presented in the *Fundamentals Manual* are copied below as Table 6.4.

Table 6.4
DAT File Records Defining Relevant Water Rights

```

** Hempstead Gage - Multiple-Reservoir System Diversion Right  *****!*****!*****!
**
WR  Hemp 900000.      MUN2 200601  2          WR-24          SystemH
WS   PK 570240.
WSBelton 457600.
WSGeorge 37100.
WS  Grang 65500.
**
** Refilling Storage in Multiple-Reservoir System Reservoirs !*****!*****!*****!
**
WR   PK                999999          WR-25          Refill  SystemH
WS   PK 570240.
WRBelton                999999          WR-26          Refill  SystemH
WSBelton 457600.
WRGeorge                999999          WR-27          Refill  SystemH
WSGeorge 37100.
WR  Grang                999999          WR-28          Refill  SystemH
WS  Grang 65500.

```


Table 6.5
Example SIM Yield-Reliability Output YRO File in Safe Yield Format

Yield Versus Reliability Table for the Following Water Supply Diversion Right(s):

```

100.000 percent: WR-24           SystemH
  0.000 percent: WR-25           Refill   SystemH
  0.000 percent: WR-26           Refill   SystemH
  0.000 percent: WR-27           Refill   SystemH
  0.000 percent: WR-28           Refill   SystemH
    
```

If more than one right, the target amount is distributed using the percentages shown above. The total number of periods is 924. The period reliability is the percentage of the periods for which at least 100.0 percent (FY record field 2; default=100%) of the target is supplied.

The FY record contains the following safe yield parameters:
 FYC(2), FYC(3), FYIN(6) are: 1 12 0.0

Total storage capacity = 1130440.0
 Inactive storage capacity = 0.0

I	L	Annual Target (ac-ft/yr)	Mean Shortage (ac-ft/yr)	Volume Actual (ac-ft/yr)	Rel (%)	n	Period Maximum Rel (%)	Storage Reserve Shortage Months	Storage Reserve (ac-ft)	Minimum Storage (ac-ft)
1	0	1200000.0	90857.1	1109142.9	92.43	831	89.94	9	1199999.9	0.0
2	1	1100000.0	67260.1	1032739.9	93.89	849	91.88	9	1100000.0	0.0
3	1	1000000.0	45795.6	954204.4	95.42	867	93.83	9	1000000.0	0.0
4	1	900000.0	29932.2	870067.8	96.67	883	95.56	7	900000.0	0.0
5	1	800000.0	19482.3	780517.7	97.56	894	96.75	6	799999.9	0.0
6	1	700000.0	13401.8	686598.2	98.09	900	97.40	6	700000.1	0.0
7	1	600000.0	8213.6	591786.4	98.63	909	98.38	5	599999.9	0.0
8	1	500000.0	4078.6	495921.4	99.18	913	98.81	5	500000.0	0.0
9	1	400000.0	951.4	399048.6	99.76	919	99.46	4	400000.0	0.0
10	1	300000.0	0.00	300000.0	100.00	924	100.00	0	300000.0	19136.1
11	1	200000.0	0.00	200000.0	100.00	924	100.00	0	200000.0	64760.4
12	1	100000.0	0.00	100000.0	100.00	924	100.00	0	100000.0	130803.4

13	2	190000.0	0.00	190000.0	100.00	924	100.00	0	190000.0	70715.7
14	2	180000.0	0.00	180000.0	100.00	924	100.00	0	180000.0	76123.5
15	2	170000.0	0.00	170000.0	100.00	924	100.00	0	170000.0	81469.2
16	2	160000.0	0.00	160000.0	100.00	924	100.00	0	160000.0	86856.6
17	2	150000.0	0.00	150000.0	100.00	924	100.00	0	150000.0	93876.6
18	2	140000.0	0.00	140000.0	100.00	924	100.00	0	140000.0	101390.8
19	2	130000.0	0.00	130000.0	100.00	924	100.00	0	130000.0	108916.0
20	2	120000.0	0.00	120000.0	100.00	924	100.00	0	120000.0	116441.2
21	2	110000.0	0.00	110000.0	100.00	924	100.00	0	110000.0	123971.9

22	3	119000.0	0.00	119000.0	100.00	924	100.00	0	119000.0	117193.8
23	3	118000.0	0.00	118000.0	100.00	924	100.00	0	118000.0	117946.8
24	3	117000.0	0.00	117000.0	100.00	924	100.00	0	117000.0	118700.0

25	4	117900.0	0.00	117900.0	100.00	924	100.00	0	117900.0	118022.2

Two versions of a FY record are copied as follows. The first version of the FY record shown on the next page is used to create the YRO file yield-reliability table presented as Table 3.5 of the *Fundamentals Manual*, which terminates with a firm yield of 322,800 acre-feet/year. The

second version of the *FY* record results in the table reproduced below as Table 6.5, which terminates in a safe yield of 117,900 acre-feet/year.

FY	1200000.	100000.	10000.	1000.	WR-24				
FY	1200000.	100000.	10000.	1000.	WR-24	SystemH	0	1	12

The YRO table in the *Fundamentals Manual* based on firm yield has the same format as Table 6.3. Addition of non-zero values for the safe yield criteria parameters FYC(1) and/or FYC(2) converts to the table format illustrated by Table 6.5 which has three additional columns. The last three columns are added if and only if FYC(1) and/or FYC(2) are non-zero (non-blank).

The modified example discussed below consists of replicating the *Fundamentals Manual* example with the following modification. FYC(2) option 1 is activated with a FYC(3) of 12 months. The resulting yield-reliability presented as Table 6.5 includes a safe yield of 117,900 acre-feet/year. The concept is to define a safe yield that is "safer" than the firm yield. A reservoir storage volume reserve is defined that consists of 12 months of the diversion target. The safe yield is defined as the maximum annual diversion target for water right WR-24 that results in (1) no diversion shortages during the simulation and (2) a minimum total storage volume in the four reservoirs equivalent to 12 months of the diversion target.

The yield-reliability table begins with a list of the water rights for which the yield-reliability analysis is performed. These are specified on the *FY* record.

FY	1200000.	100000.	10000.	1000.	WR-24	SystemH	0	1	12
----	----------	---------	--------	-------	-------	---------	---	---	----

Water right *FYWRID* in *FY* record field 7 and all water rights with a water group identifier *FYGROUP* referenced in *FY* record field 8 are included. Entering WR-24 for *FYWRID* in the *FY* record above is actually redundant (unnecessary) since water right WR-24 is also identified by the group identifier SystemH. The *FYGROUP* identifier SystemH is not included on the *FY* record in the example presented in the *Fundamentals Manual* because identification of reservoir refill rights WR-25, WR-26, WR-27, and WR-28 is not necessary with the firm yield version of the yield-reliability analysis. *FYGROUP* identifier SystemH is required for the safe yield version of the yield-reliability analyses to define the reservoirs included in the reservoir storage reserve.

The following discussion focuses on defining safe yield based on a reservoir storage reserve, which is a minimum allowable storage volume limit. A water supply failure is declared if storage content falls below the specified storage reserve volume. Storage reserve computations are applicable only to water rights that refill reservoir storage. Water right types are defined in Chapter 4 and are specified for each water right in field 6 of the *WR* record. Default type 1 water rights refill reservoirs draw-down by water supply diversions. Type 3 water rights refill reservoirs drawn down by hydroelectric power operations. Types 2, 3, 4, and 6 do not include refilling of reservoir storage. *FY* record storage reserves apply only to water right types 1 and 3.

As indicated in Table 6.4, WR-4 is a type 2 water right. Water rights WR-25, WR-26, WR-27, and WR-28 have no diversion targets and thus serve the sole purpose of refilling storage in the four reservoirs that supply the water right WR-24 diversion requirement. Group identifier SystemH is included on the *FY* record to include water rights WR-25, WR-26, WR-27, and WR-28 in the safe yield storage reserve computations.

As indicated in Tables 6.4 and 6.5, a set of multiple water rights define multiple-reservoir system operation of four reservoirs with a total capacity of 1,130,440 acre-feet of which none of the storage volume happens to be contained in inactive pools. The term storage volume in the following paragraphs refers to active conservation pool storage that does not include inactive pools. Storage volumes used in the computational algorithm are exclusive of inactive storage.

The example activates FYC(2) option 1 with a FYC(3) of 12 months to define a reservoir storage volume reserve. The safe yield is the maximum annual WR-24 diversion target that meets the following criteria: (1) no diversion shortages for the WR-24 diversion and (2) the total storage contents of the four reservoirs do not fall below the defined storage reserve volume at any time during the simulation. A water supply failure occurs if either criterion is not fulfilled.

FYC(3) is any specified number of months that defines a period ending in the month of the hydrologic period-of-analysis simulation for which the end-of-month storage volume is a minimum. If exactly the same minimum storage volume occurs in more than one month, the first occurrence is adopted for defining the FYC(3)-month period for computing the required reservoir storage reserve volume. The reserve storage volume in the example is computed as the summation of the monthly water right WR-24 diversion targets in each of the 12 months that end with the 12th month being the month of the simulation in which the summation of the end-of-month storage volumes in the four reservoirs is a minimum. If FYC(3) is changed to 30 months on the *FY* record, the required storage reserve volume would be the total diversion target during the 30 months preceding the critical most severe drawdown.

The FYC(2) options for computing the safe-yield storage volume reserve are listed in Table 6.2 and reiterated as follows. Option 1 is adopted for the Table 6.5 example.

Option 1: The storage reserve is the summation of WR-24 diversion targets during the FYC(3) months preceding the most severe draw-down of the four reservoirs.

Option 2: The storage reserve is the summation of WR-24 diversion targets plus the net evaporation-precipitation volumes of the four reservoirs during the FYC(3) months preceding the most severe draw-down of the four reservoirs.

Option 3: The storage reserve is based on net reservoir drawdown during the FYC(3) month period which reflects all factors affecting reservoir storage including inflows as well as diversions/releases, and net evaporation-precipitation. The storage reserve is computed as the summation of the end-of-month storage volume of the four reservoirs in the first month of the FYC(3)-month long period less the corresponding end-of-month storage volume in the last month. Zero is adopted if the computed quantity is negative indicating the storage volume experienced a net increase rather than decrease.

Option 4: The storage reserve volume in acre-feet is specified by the model-user as the input variable FYIN(6). FYC(3) is not specified since the FYC(3) period has no relevance.

The storage reserve is applied in the same manner regardless of which FYC(2) option is selected to define its computation. The concept is to define a reservoir storage volume such that a drawdown below that level means that the diversion target is greater than a defined safe yield.

The storage volume represents active conservation storage above designated inactive pools. The four reservoirs in the example have no inactive pools defined on their *WS* records. However, in the case of reservoirs with inactive pools, the computed storage reserve is active pool storage above the inactive pools. Inactive pools defined on *WS* records can also be treated as a mechanism for defining additional storage reserve volume.

The same variables are tabulated in the first seven columns of Tables 6.3 and 6.5 or any YRO file yield-reliability table. A positive FYC(2) results in the last three columns of Table 6.5 being added. The "Maximum Shortage Months" is the maximum number of consecutive months with less than FYIN(1) of the target supplied. The FYC(2) safe yield criterion is that the "Minimum Storage" in the last column of the table equal or exceed the "Storage Reserve" in the preceding column. This is the minimum active conservation pool storage content of the four reservoirs that occurred during the simulation.

Stream Flow Availability in the Water Rights Priority Sequence

A *SIM* feature controlled by the *ZZ* record and associated *TABLES* routines controlled by the *4ZZZ* and *4ZZF* records are designed to facilitate assessments of the effects of other water rights located throughout the river basin on the amount of stream flow that is available to water users at particular locations of concern. For each control point specified with a *SIM ZZ* record, regulated flows, available flows, and upstream reservoir releases are tabulated in a *ZZZ* file after each individual water right is simulated in the priority loop. These monthly flows are recorded at the beginning of the water rights loop and after each individual water right is simulated in the priority sequence. *TABLES* reads the *ZZZ* file and organizes the flow information.

All *SIM* output *OUT* file variables are defined in Chapter 5 and listed in Table 5.1. An identifying label is listed in the second column of Table 5.1. Three of these previously defined variables (regulated flows, available stream flows, and upstream reservoir releases), labeled 2REG, 2ASF, and 2URR in Table 5.1, are included in the *ZZZ* file. Intermediate available stream flows (2ASF in Table 5.1) in the water rights priority sequence become unappropriated flows (2UNA) after the most junior water right is simulated. The reservoir releases (2URR) included in the *ZZZ* table are a component of regulated flows (2REG) and include only releases from reservoirs located at or upstream of a control point that are made to meet water right diversion, storage, or instream flow requirements at a control point located further downstream.

The *ZZZ* file table may be read directly with any editor. The *TABLES 4ZZZ* and *4ZZF* records activate *TABLES* options for reading a *ZZZ* file and organizing the simulation results in optional time series formats or developing frequency tables. The *4ZZZ* record builds time series tables in optional formats or *DSS* files, and the *4ZZF* record creates frequency analysis tables similar to the *2FRE* record frequency tables discussed in Chapter 7.

During each month of the *SIM* simulation, flows at designated control points are tabulated in the *ZZZ* file at the beginning of the water rights priority loop and after each water right is simulated in the priority sequence. By default, all water rights from the most senior to most junior are included in the tabulation. However, an optional parameter entered on the *ZZ* record sets a minimum flow change required for a water right to be included in the table. Monthly flow volumes are tabulated after a water right is simulated only if the change in either the regulated flow,

available flow, or upstream release equals or exceeds the specified limit at one or more of the control points being considered. Another option allows the tabulation to stop after reaching a specified water right in the priority sequence. The larger Texas WAM System datasets contain hundreds of water rights. These ZZ record options allow the length of the ZZZ file table to be greatly reduced. TABLES deals with variations in water right listings between months by assigning flows to missing rights by repeating flows for the preceding right listed.

Instructions for applying the SIM ZZ record and TABLES 4ZZZ and 4ZZF records are provided in Chapters 3 and 5 of the Users Manual. Incorporation of these features in the example presented in the Fundamentals Manual results in the following Tables 6.6, 6.7, and 6.8.

Table 6.6
Beginning of Example ZZZ File Created with ZZ record

REGULATED AND AVAILABLE STREAMFLOWS COMPUTED IN WATER RIGHTS
PRIORITY SEQUENCE AT CONTROL POINTS SPECIFIED BY ZZ RECORD

First year and number of years: 1940 78
Number of water rights and control points: 30 2

Control Point		George			Grang					
Year	M	Water Right	M	WR	Reservoir Releases	Regulated Flow	Available Flow	Reservoir Releases	Regulated Flow	Available Flow
1940	1	*** Beginning **	1	0		156.0	156.0		502.0	502.0
1940	1	WR-10	1	16	0.0	0.0	0.0	0.0	1147.1	1147.1
1940	1	WR-11	1	17	0.0	0.0	0.0	0.0	0.0	0.0
1940	2	*** Beginning **	2	0		1320.0	1320.0		4249.0	4249.0
1940	2	WR-10	2	16	0.0	0.0	0.0	0.0	3714.8	3714.8
1940	2	WR-11	2	17	0.0	0.0	0.0	0.0	0.0	0.0
1940	3	*** Beginning **	3	0		464.0	464.0		1493.0	1493.0
1940	3	WR-10	3	16	0.0	0.0	0.0	0.0	1844.8	1844.8
1940	3	WR-11	3	17	0.0	0.0	0.0	0.0	0.0	0.0
1940	3	WR-24	3	24	0.0	0.0	0.0	10230.4	10230.4	0.0
1940	4	*** Beginning **	4	0		4019.0	4019.0		12931.0	12931.0
1940	4	WR-10	4	16	0.0	0.0	0.0	0.0	9793.2	9793.2
1940	4	WR-11	4	17	0.0	0.0	0.0	0.0	0.0	0.0
1940	5	*** Beginning **	5	0		4673.0	4673.0		15037.0	15037.0
1940	5	WR-10	5	16	0.0	1062.6	1062.6	0.0	12464.5	12464.5
1940	5	WR-11	5	17	0.0	1062.6	1062.6	0.0	2939.4	2939.4
1940	6	*** Beginning **	6	0		22485.0	22485.0		72349.0	72349.0
1940	6	WR-10	6	16	0.0	20059.2	20059.2	0.0	71234.6	71234.6
1940	6	WR-11	6	17	0.0	20059.2	20059.2	0.0	67792.6	67792.6
1940	7	*** Beginning **	7	0		15357.0	15357.0		49413.0	49413.0
1940	7	WR-10	7	16	0.0	11931.1	11931.1	0.0	47380.4	47380.4
1940	7	WR-11	7	17	0.0	11931.1	11931.1	0.0	41182.5	41182.5

Note: The ZZZ file is actually much longer extending from January 1940 through December 2017.

The ZZZ file partially reproduced as Table 6.6 was created by inserting the following ZZ record in the DAT file for the example presented in the Fundamentals Manual.

ZZ 2 0.01 George Grang

All other *SIM* input and output remain unchanged. The time series and frequency tables reproduced as Tables 6.7 and 6.8 were developed with the data from the *ZZZ* file with *TABLES* using the 4*ZZZ* and 4*ZZF* records shown on the next page.

The *ZZZ* file covers the entire period-of-analysis, which is 1940-2017 for the example from the *Fundamentals Manual* used here. Only the first seven months are shown in Table 6.6. The year and month are tabulated in the first two columns of the *ZZZ* file table. The month (M) in the second column is an integer between 1 and 12 repeating each year, and the month (M) in the fourth column is an integer between 1 and 936 covering the 936 months in the 1940-1997 period-of-analysis. The third column is the water right identifier. The sixth column with heading WR is the integer water right index with 1 denoting the most senior water right in the *SIM* input dataset. The table includes flows at control points with identifiers George and Grang.

The *ZZZ* table is constructed as the simulation proceeds through the water rights priority sequence each month. The default is to include all water rights in the table. However, in creating the *ZZZ* file of Table 6.6, a *ZZ* record option was used that allows specification of a minimum flow change required to include a water right in the table. A minimum limit of 0.01 acre-feet was entered on the *ZZ* record for this example, which essentially means a non-zero change. Thus, an additional row is added to the *ZZZ* file table only if at least one of the flows in the row is different from the preceding row of the table in an amount of at least 0.01 acre-feet. With a total of 30 water rights in the example, this option greatly reduces the length of the table.

Using the third month (March 1940) as an example, the *ZZZ* file is interpreted as follows. The purpose of the *ZZZ* file is to display the impacts of all water rights on regulated and available flows at each of the two control points with identifiers George and Grang. At the beginning of the water rights priority loop for the third month, prior to simulating any of the water rights, the March 1940 regulated and available flow are both 464.0 acre-feet/month at control point George and 1,493.0 acre-feet/month at control point Grang. The initial flows are always naturalized flows plus, if next-month return flow or next-month hydropower options are activated, any return flows or hydropower releases from the preceding month.

In month 3 (March 1940), one or more of the flows are affected by water rights WR-10, WR-11, WR-15, and WR-24. The relative priority rankings of these four water rights are 16, 17, 22, and 24. The 15 other rights senior to WR-10 do not affect the flows at control point Grang. After simulating water right WR-10, the regulated and available flows are reduced to 0.0 at George and are increased to 1,844.8 acre-feet at Grang. The increase at Grang is due to return flow from a diversion at George located upstream. Water right WR-11 reduces the regulated and available flows to zero at both George and Grang. The flows at George remain zero throughout the remainder of the priority sequence simulation. Water right WR-24 increases the regulated flow at Grang to 10,230.4 acre-feet. WR-24 is a diversion at a downstream control point for which releases are made from the reservoir at control point Grang. The reservoir release column of the *ZZZ* file table is a component of regulated flow, which for the 10,230.4 acre-feet flow happen to account for the total regulated flow.

Only tables for control point Grang are shown in Tables 6.7 and 6.8. The data lines for years 1980-1999 are deleted to condense Table 6.7 to fit on a single page.

Table 6.7
4ZZZ Time Series Table for the Example

AVAILABLE FLOWS (AC-FT) AT CONTROL POINT Grang AFTER WATER RIGHT WR-15

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.0	0.0	0.0	0.0	2939.4	67792.6	41182.5	0.0	0.0	0.0	76079.7	98195.0	286189.2
1941	47656.0	71542.7	65401.1	79236.4	75489.1	52012.9	9078.3	0.0	0.0	0.0	0.0	0.0	400416.5
1942	0.0	0.0	0.0	16669.8	10222.1	34301.1	0.0	0.0	881.6	21865.9	5164.3	4418.2	93523.0
1943	3659.0	762.1	1386.1	0.0	894.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6701.8
1944	0.0	10652.1	37557.7	16457.3	82739.6	40723.6	0.0	0.0	0.0	0.0	0.0	3583.3	191713.6
1945	46758.7	43908.4	37651.0	57412.8	20691.8	30206.7	1537.5	0.0	0.0	0.0	733.0	942.3	239842.2
1946	5745.6	19294.9	24471.9	17131.2	21778.3	2715.5	0.0	0.0	0.0	0.0	17495.8	27601.6	136234.8
1947	35154.5	23319.4	22904.8	17011.6	6842.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	105233.1
1948	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1949	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1951	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1952	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1953	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1954	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1955	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1956	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1957	0.0	0.0	0.0	57790.9	60921.4	76898.1	0.0	0.0	0.0	23236.1	27306.5	22399.5	268552.5
1958	20272.1	81113.5	44544.8	15472.9	19638.4	3789.0	0.0	0.0	0.0	444.4	1010.1	964.2	187249.4
1959	246.0	2837.4	799.2	6190.8	2437.7	0.0	0.0	0.0	0.0	111460.7	19725.3	60746.1	204443.2
1960	46936.1	37634.5	20139.9	9498.2	1557.8	0.0	0.0	0.0	0.0	0.0	0.0	20163.2	135929.7
1961	50135.0	91187.5	27523.9	7371.2	856.9	1884.5	14471.8	0.0	1591.7	1664.4	2199.2	2482.4	201368.5
1962	1744.3	911.0	0.0	1837.3	1503.1	3563.1	0.0	0.0	0.0	0.0	0.0	0.0	9558.8
1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1965	0.0	0.0	0.0	8642.4	114907.0	19118.8	266.1	0.0	7040.8	2686.0	12742.6	28208.0	193611.7
1966	15145.0	20890.0	17325.3	55119.0	37843.6	6862.2	0.0	0.0	10329.8	0.0	0.0	0.0	163514.9
1967	0.0	0.0	0.0	0.0	1089.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1089.8
1968	65187.7	35799.1	50669.2	30733.5	54936.4	30100.1	10842.7	0.0	1800.5	0.0	3059.3	7464.7	290593.2
1969	3142.9	11365.6	17459.1	49443.6	43843.3	4310.4	0.0	0.0	0.0	0.0	0.0	0.0	129564.9
1970	0.0	0.0	55391.6	24108.6	43060.9	14417.8	0.0	0.0	0.0	0.0	0.0	0.0	136978.9
1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1973	0.0	7788.0	14683.7	24006.5	28854.9	6869.1	0.0	0.0	0.0	23866.3	19600.2	7774.1	133442.8
1974	11262.6	6024.0	3999.1	1876.3	43149.5	0.0	0.0	0.0	0.0	0.0	49319.4	18660.3	134291.2
1975	15999.1	69651.6	16338.1	7880.1	82766.1	38379.1	9978.2	6662.8	616.9	0.0	0.0	0.0	248272.0
1976	0.0	0.0	0.0	29486.3	40302.7	11587.5	17611.1	0.0	0.0	2741.9	3958.8	13147.4	118835.7
1977	11907.2	30343.6	14171.0	83985.3	22229.4	2037.6	0.0	0.0	0.0	0.0	0.0	0.0	164674.1
1978	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1979	0.0	0.0	747.0	33283.5	57790.5	41609.5	11869.3	1375.3	0.0	0.0	0.0	0.0	146675.1
Lines of data for 1980 through 1999 are omitted in order to fit the table on a single page.													
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001	10413.3	9646.6	42839.2	19920.8	16872.4	9927.5	0.0	0.0	0.0	0.0	0.0	33842.2	143462.0
2002	8443.9	5419.0	4639.4	3586.7	0.0	0.0	55260.2	0.0	0.0	2831.6	14431.5	35120.5	129732.8
2003	25086.3	43671.8	34462.6	8226.9	0.0	32.0	0.0	0.0	0.0	0.0	0.0	0.0	111479.6
2004	0.0	0.0	0.0	0.0	5530.0	33828.0	7667.6	8073.4	0.0	11165.6	141423.1	30353.6	238041.3
2005	19843.4	32638.6	50489.2	14467.2	7168.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	124606.7
2006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	0.0	0.0	44833.1	17157.9	69290.6	156140.4	130166.6	25571.0	15221.7	3042.6	2101.4	1877.3	465402.6
2008	1212.3	551.5	3727.0	2957.0	14526.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22973.8
2009	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25367.3	24291.1	49658.4
2010	46057.6	63969.6	49158.9	19755.6	3170.7	1766.4	0.0	0.0	42150.4	787.4	377.7	315.0	227509.3
2011	2604.8	438.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3043.0
2012	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2013	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	0.0	0.0	0.0	0.0	93009.7	32376.1	5158.6	0.0	0.0	24682.7	32528.0	38774.3	226529.4
2016	1465.8	0.0	7096.1	87691.8	103821.6	10767.2	0.0	40130.4	0.0	0.0	0.0	14597.3	265570.2
2017	21964.2	8775.7	9927.6	5821.6	4829.4	0.0	0.0	52916.3	11607.8	0.0	1414.3	13316.6	130573.5
MEAN	9009.6	14616.6	13078.4	14206.5	20398.5	16505.4	4946.6	1762.8	1357.9	3347.7	6361.0	10003.1	115593.9

Table 6.8
4ZZF Frequency Analysis Table for the Example

FREQUENCY TABLE FOR AVAILABLE FLOWS AT CONTROL POINT Grang

WR	WATER RIGHT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
		MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
0	Beginning	16074.9	25765.	0.0	0.0	0.0	62.8	456.8	1752.0	3711.	5454.	8659.	20102.	45868.	212283.
1	IF-1	16074.3	25765.	0.0	0.0	0.0	57.4	456.8	1752.0	3711.	5454.	8659.	20102.	45868.	212283.
4	WR-1	16074.3	25765.	0.0	0.0	0.0	57.4	456.8	1752.0	3711.	5454.	8659.	20102.	45868.	212283.
6	WR-14	16074.2	25765.	0.0	0.0	0.0	44.6	456.8	1752.0	3711.	5454.	8659.	20102.	45868.	212283.
7	WR-20	16074.2	25765.	0.0	0.0	0.0	44.6	456.8	1752.0	3711.	5454.	8659.	20102.	45868.	212283.
8	WR-22	16073.7	25765.	0.0	0.0	0.0	4.8	456.8	1752.0	3711.	5454.	8659.	20102.	45868.	212283.
9	WR-16	16072.4	25766.	0.0	0.0	0.0	0.0	450.4	1752.0	3711.	5454.	8659.	20102.	45868.	212283.
10	WR-17	16069.7	25768.	0.0	0.0	0.0	0.0	445.0	1752.0	3711.	5454.	8659.	20102.	45868.	212283.
11	WR-13	16067.1	25770.	0.0	0.0	0.0	0.0	436.6	1752.0	3711.	5454.	8659.	20102.	45868.	212283.
12	WR-19	16066.6	25770.	0.0	0.0	0.0	0.0	418.0	1752.0	3711.	5454.	8659.	20102.	45868.	212283.
13	WR-21	16057.4	25775.	0.0	0.0	0.0	0.0	343.0	1726.0	3711.	5454.	8659.	20102.	45868.	212283.
14	WR-8	16052.4	25778.	0.0	0.0	0.0	0.0	306.0	1721.0	3690.	5454.	8659.	20102.	45868.	212283.
16	WR-10	14641.5	23688.	0.0	0.0	0.0	93.6	793.2	2187.8	3813.	5036.	7688.	17410.	40088.	200782.
17	WR-11	9670.4	22217.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	47.	7788.	34026.	200139.
18	WR-3	9664.1	22219.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7788.	34026.	200139.
19	WR-12	9641.8	22228.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7788.	34026.	200139.
22	WR-15	9632.8	22230.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7788.	34026.	200139.
24	WR-24	9620.0	22234.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7788.	34026.	200139.
25	WR-4	9656.8	22220.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	265.	7788.	34026.	200139.
26	WR-5	9616.5	22235.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	7788.	34026.	200139.

With the 4ZZZ and 4ZZF input records reproduced below, TABLES reads the ZZZ file of Table 6.6 and creates the tables reproduced as Tables 6.7 and 6.8 which are stored in the TABLES output TOU file.

```

4ZZZ    1    0    0    3    2    WR-15
IDEN    George    Grang
4ZZF    3    0    -2

```

As discussed in Appendix C, the input files for the examples in this *Reference Manual* and the other WRAP manuals are available along with the WRAP programs. All of the examples are quickly replicated by executing the programs with the datasets. Thus, the complete SIM output ZZZ file and TABLES output TOU file from which Tables 6.6, 6.7, and 6.8 are copied can be easily generated by the reader. The complete simulation results include similar tables for all of the specified control points and water rights.

The 4ZZZ record time series table reproduced as Table 6.7 is for available stream flows at the Grang control point. The flows in the table represent flow volumes available to a right located at the Grang control point during each month of the 1940-1997 hydrologic period-of-analysis after consideration in the priority sequence simulation of water right WR-15 and all other rights that are senior to WR-15. Water right WR-15 has an integer priority rank identifier of 22 shown in Tables 6.6 and 6.8 meaning 21 other more senior rights are found in the SIM input. The flows in Table 6.7 represent the amount of stream flow available at control point Grang in the water rights priority sequence between water right WR-15 with a priority rank WR of 22 and water right WR-23 with rank WR of 23. Similar 4ZZZ tables can be easily created from the ZZZ file of Table 6.6 for either of the three flow variables (reservoir releases, regulated flows, available flows) at either of the two

control points (George and Grang) at the beginning of the priority sequence or after simulation of either of the 22 water rights included in the ZZZ file. The flows can also be written in a columnar format for transport to a spreadsheet program or as records in a DSS file for plotting with *HEC-DSSVue*.

The 4ZZF frequency table of Table 6.8 was developed by *TABLES* based on computing the mean and standard deviation (Equations 7.6 and 7.7) and applying the relative frequency formula (Equation 7.3) similarly as for the 2FRE frequency table of Table 7.12 of Chapter 7. A 4ZZF record frequency table is developed from the ZZZ file for a selected variable at a selected control point. With no specific month such as August specified, all 936 months of the 1940-2017 simulation are included in the computations. The available flows after considering water right WR-15 in the priority sequence have a mean of 9,632.8 acre-feet/month, and a volume of 7,788 ac-ft/month is equaled or exceeded during 25 percent of the months. The available flow at this point in the priority sequence is at least 34,026 ac-ft/month during ten percent of the time.

Beginning-Ending Storage Options

SIM has several options for specifying storage content of each reservoir at the beginning of the simulation. The default beginning-of-simulation storage content is the maximum storage capacity entered on a *WS* record for a water right associated with the reservoir. Optionally, the initial storage content may be entered on the *WS* record for each reservoir. If not otherwise specified, the storage at the beginning of the simulation is set equal to the reservoir storage capacity by default.

SIM also includes a set of beginning-ending storage (BES) options activated by an entry for input parameter BES on the *JO* record. The BES options provide capabilities for setting beginning storages for numerous reservoirs more conveniently than using the *WS* record for each individual reservoir. Though setting beginning storages for other types of applications may be useful as well, the beginning-ending storage (BES) feature is motivated primarily by situations in which beginning storage is set equal to ending storage.

In past Texas WAM System applications of WRAP, beginning-of-simulation reservoir storage has typically been set at capacity for all reservoirs. The hydrologic period of analysis has been selected to begin with a series of relative wet years during which the assumption of initially full reservoirs is reasonable. However, beginning-of-simulation storage may be an issue in some applications. The initial storage content less the storage content at the end of the simulation represents extra water that could result in estimated reliabilities being higher than they should.

The BES feature is based on setting beginning and ending storages equal, which reflects the concept of a cycling hydrologic simulation period. A fixed simulation period is assumed to conceptually repeat forever. For example, hydrology may be represented by a set of naturalized flows and evaporation rates covering a 1940-2017 period-of-analysis. The 78-year hydrologic sequence is assumed to repeat forever. The sequences of naturalized flows and evaporation rates starting in January 1940 are assumed to repetitively follow completion of the sequences in December 2017. Cycling results in a steady state condition with the storages at the beginning and ending of the 78 year hydrologic cycle being identical. The cycling premise is incorporated into models by setting the storages at the beginning and ending of the simulation equal.

One approach for setting the beginning and ending storages equal is to perform the simulation two or more times. The first simulation is based on assumed beginning storages, such as assuming reservoirs are full to capacity. For the second and subsequent (as needed) simulations, the beginning storage is set equal to ending storage from the previous simulation. One iteration may be sufficient to achieve the same beginning and ending storage conditions in some cases. Additional iterations may be necessary. The beginning-ending storage (BES) switch on the *JO* record activates options that are based on an initial simulation just to determine the storage at the end of the simulation. A second simulation begins with the beginning storages set equal to these ending storages. The ending storages may be recorded in a file and read as beginning storages with the process manually repeated iteratively. A second simulation may also be repeated automatically within *SIM* either with or without recording the storages in a BES file. Thus, the model user can quickly run *SIM* multiple times to iteratively determine a set of beginning storage content levels that result in the simulation ending with the same storage levels.

SIM also has options in which diversion return flows and hydropower releases are returned to the stream system the next month after the water supply diversion or hydropower release occurs. The BES options include a feature that also cycles the next-month option return flows and hydropower releases. The flows from the last month of the initial simulation re-enter the stream system at the beginning of the repeat simulation.

The beginning-ending storage options are selected by the parameter *BES* in *JO* record field 5. The six alternative options are as follows.

1. *BES* of 1 specifies that the storage content of each reservoir at the end of the simulation be written to a file with the filename extension BES.
2. *BES* of 2 specifies that initial storages at the beginning of the simulation be read from the BES file.
3. For *BES* = 3, the storages at the beginning of the simulation are read from the BES file, and the storages at the end of the simulation are written to the BES file. Thus, option 3 combines options 1 and 2.
4. With *BES* = 4, the simulation is performed twice; the storages at the end of the first simulation are written to the BES file; and the storages at the beginning of the second simulation are read from the BES file. Thus, the storages at the beginning of the second simulation are set equal to the storages at the end of the first simulation. The BES file contains the storages at the end of the first simulation and beginning of the second simulation. The final output file contains the results of the second simulation.
5. *BES* = 5 performs a dual simulation identical to option 5 except the BES file is not created. The storages at the end of the first simulation become the storages at the beginning of the first simulation without being written to a file.
6. *BES* = 6 creates a listing with reservoir-related water rights information added that cannot be read by *SIM*, but rather is designed just for information for the model-user.

BES options 4 and 5 also address return flows and hydropower releases. With the next-month return flow and next-month hydropower options in effect, BES options 4 and 5 return the return flows at the end of the simulation back to the beginning.

Options 1, 2, 3, and 4 involve writing ending storages to a file and/or reading beginning storages from the file. Using options 1, 2, and 3, two or more simulations may be performed by repeated runs of *WRAP-SIM*. Options 4 and 5 involve an automatic second simulation with second simulation beginning storages set equal to the storages at the end of the first simulation. Options 4 and 5 also return next-month option hydropower releases and return flows from the end of the simulation back to the beginning.

All options except option 5 require activation of a BES file, which is opened automatically. A BES file written by *SIM* includes all reservoirs listed in the conventional order established when the DAT file was read. A BES file read by *SIM* may include any number of the reservoirs but they must be listed in the order of the numeric identifiers. The BES file may be manually edited to change storage amounts or delete/add reservoirs. A reservoir may be removed either by entering a -1 for its storage amount or by deleting its entry from the file. If a BES file is read, for any reservoirs not included in the file, beginning storages are set by *WS* record fields 3 and 8 in the conventional manner.

General Framework for WRAP Capabilities

WRAP is a flexible modeling system that can be applied in various ways depending on the particular situation. Conventional strategies for applying the WRAP programs *SIM* and *TABLES* employed in conjunction with the Texas WAM System use the modeling capabilities described in this *Reference Manual* and companion *Users Manual*. *SIM* is covered in Chapters 2, 3, 4, 5, 6 of this *Reference Manual* and Chapters 2 and 3 of the *Users Manual*. *SIMD* is covered in the *Daily Manual* and Chapter 4 of the *Users Manual*. *TABLES* is documented by Chapter 7 of this *Reference Manual* and Chapter 5 of the *Users Manual*.

Chapter 5 of this manual focuses on the time series variables of *SIM* simulation results stored in the default OUT or alternative SOU or DSS output files and *TABLES* capabilities for reorganizing these data and performing frequency, reliability, and water budget analyses. The preceding sections of Chapter 6 discuss organization and analyses of *SIM* simulation results associated with other auxiliary *SIM* output files. WRAP applications of HEC-DSS and *HEC-DSSVue* are outlined in Chapter 6 of the *Users Manual*. *HEC-DSSVue* is explained in great detail by its own user's manual available from the HEC with the software.

Short-term conditional reliability modeling is covered in Chapter 8 of this *Reference Manual* and Chapter 5 of the *Users Manual*. The daily WRAP modeling system expands the concepts and methods presented in this *Reference Manual* as explained in the *Daily Manual*. The WRAP programs *HYD* and *DAY* facilitate compilation and updating of hydrology input data for the simulation models *SIM* and *SIMD* as described in the *Hydrology* and *Daily Manuals*.

The *SIM* and *TABLES* features outlined in this *Reference Manual* and companion *Users Manual* have been extensively applied by the water management community in Texas. Most of the features outlined in Chapters 1 through 7 of this *Reference Manual* are in routine use. The *SIM* and *TABLES* conditional reliability modeling capabilities covered in Chapter 8 of this *Reference Manual* and the modeling capabilities provided by the other WRAP programs and documented by the *Daily*, *Hydrology*, and *Salinity Manuals* have experienced relatively limited practical application to date but their use is increasing.

Conventional Long-term Water Availability Modeling

The Water Availability Modeling (WAM) System discussed in Chapter 1 combines the generalized WRAP and input datasets listed in Table 1.2 for all of the river basins of Texas. The original implementation of the WAM System during 1997-2003 consisted of developing input datasets and modeling a specified set of water management and use scenarios for each of the river basins. The modeling system has since then continued to be extensively applied in the preparation and evaluation of water right permit applications, regional and statewide planning studies, and other water management activities. The WRAP programs have been greatly expanded and improved in response to challenges encountered and experience gained in modeling the diverse individual river basins of the state.

WRAP is routinely applied in regional and statewide planning studies and water rights regulatory activities in Texas using the input datasets from the TCEQ WAM System. WRAP users employed by water agencies, consulting firms, and universities modify these data files to model the alternative water resources development projects, river regulation strategies, and water use scenarios being investigated in their studies. The WAM System datasets are periodically updated by the Texas Commission on Environmental Quality (TCEQ) to reflect changes in water right permits and water management practices and refinements in modeling capabilities.

WRAP is applicable essentially any place in the world for modeling a comprehensive range of water resources development, management, and allocation practices and river/reservoir system configurations and operations. For river basins outside of Texas, model users must develop the input datasets required for their particular applications. New and different input datasets may also be developed for different types of applications in Texas.

A simulation study typically involves many executions of *SIM* simulating alternative water resources development, management, allocation, and use scenarios. The river/reservoir system is simulated with *SIM* with the results reorganized with *TABLES* and *HEC-DSSVue* for display and analysis purposes. The primary *SIM* simulation time series results recorded in the OUT file are input to *TABLES* to perform user-specified reliability, frequency, water accounting, and other analyses. The same *SIM* simulation time series output is optionally recorded in a *SIM* DSS output file for transfer to *HEC-DSSVue* for plotting graphs or other analysis. *TABLES* options allow *SIM* output with or without further *TABLES* adjustments to be transported to *HEC-DSSVue*. *TABLES* can read *SIM* and *SIMD* input and output *DSS* files and any other *DSS* file.

Incorporation of the USACE Hydrology Engineering Center (HEC) Data Storage System (DSS) and the *HEC-DSSVue* component of DSS into the WRAP modeling system evolved over several years. The original motivation for employing DSS and *HEC-DSSVue* with WRAP was *HEC-DSSVue* capabilities for plotting time series graphs. DSS and *HEC-DSSVue* are fully integrated in the April 2019 version of WRAP, contributing greatly to the data management and statistical and mathematical as well as graphics capabilities of the combined modeling system.

Developing and Updating Hydrology Input Data

The WRAP program *HYD* described in the *Hydrology Manual* [4] is designed to assist in developing and updating the hydrology files of stream flows and net evaporation-precipitation

depths for the *SIM* input dataset. Most of the hydrology datasets for the Texas WAM System were originally developed during 1998-2001 prior to completion of the initial program *HYD*. Microsoft Excel was used for most of the computational tasks that have since been incorporated into *HYD*. The original *HYD* developed during 1998-2000 was significantly expanded during 2007-2008, 2011-2012, and recently. The *Hydrology Manual* documents recently developed hydrologic modeling methodologies for more efficiently extending the hydrologic period-of-analysis of the existing datasets to the present. The *Daily Manual* discusses the compilation of daily flow pattern hydrographs and routing parameters required for a daily *SIMD* simulation.

Condensed datasets with a reduced number of control points, water rights, and reservoirs can also be developed with the monthly naturalized flows input to the *SIM* simulation being replaced with flows reflecting specified water use and infrastructure [35, 36].

Short-Term Conditional Reliability Modeling (CRM)

The WRAP modeling capabilities presented in Chapters 1 through 7 of this *Reference Manual* deal with a long term simulation, with typically a hydrologic period-of-analysis of at least 50 years, designed to support planning studies and evaluation of water right permit applications. Chapter 8 covers conditional reliability modeling (CRM) designed for evaluating stream flow and reservoir storage conditions and water supply capabilities over a short time frame ranging from one month to several months to perhaps one or several years conditioned on given initial reservoir storage levels. *TABLES* develops CRM frequency and reliability relationships from *SIM* or *SIMD* monthly simulation results. Although CRM is based on monthly simulation results, a *SIMD* simulation can be performed at a daily computational time step with the simulation results aggregated to monthly quantities. CRM capabilities have been demonstrated by application to reservoir system operations in the Brazos River Basin [37, 38]

Salinity Simulation

Development of the WRAP program *SALT* and associated salinity-related routines in *TABLES* described in the *Salinity Manual* [6] was motivated by natural salt pollution in the upper watersheds of several river basins in Texas and neighboring states that severely constrains water supply capabilities of major river/reservoir systems [26]. A salinity tracking simulation begins with a regular *SIM* simulation. *SALT* reads water quantity data from the *SIM* output file along with additional input data regarding salt concentrations and loads of flows entering the river system. The model computes concentrations of the water quality constituents in the regulated stream flows, diversions, and reservoir storage contents throughout the river basin. Options in *TABLES* organize the salinity simulation results as concentration and load time series and frequency tables, supply reliability tables, and summary tables. Salt loads and concentrations can be stored in a DSS file for plotting and analysis with *HEC-DSSVue*. Development of *SALT* was supported by a WRAP salinity simulation study of the Brazos River Basin [39, 40].

Daily Modeling System

The expanded capabilities documented in the *Daily Manual* [5] represent another major recent direction in WRAP modeling. Daily simulation is much more complex than monthly due to the need to incorporate flow forecasting and routing and flow disaggregation. The daily *SIMD*

simulation model includes options for disaggregating monthly naturalized stream flows to daily, flow forecasting, routing, conversion of monthly water demand targets to daily, simulation of flood control reservoir operations, and tracking of environmental high pulse flows. *TABLES* includes routines for reliability and frequency analyses (including flood frequency analysis) of daily *SIMD* simulation results.

Although the greater detail provided by a daily computational time step can also be useful in modeling water supply and hydropower operations, modeling environmental standards and their impact on other water rights was the primary motivation for creating the daily WRAP modeling system. The monthly *SIM* environmental instream flow modeling and analysis capabilities described in this *Reference Manual* can be performed significantly more accurately with a daily time step. The daily *SIMD* also includes features for modeling high pulse environmental flow requirements that are not possible with the monthly *SIM*.

A strategy for combining the daily and monthly versions of WRAP to incorporate Senate Bill 3 (SB3) environmental flow standards in the TCEQ Water Availability Modeling (WAM) System is outlined in the *Daily Manual* [5] and employed with the Brazos WAM [44]. Daily instream flow targets for SB3 environmental flow standards are computed in a daily *SIMD* simulation, summed to monthly totals within *SIMD*, and recorded in the *SIMD* output DSS file. The monthly instream flow targets are converted to target series *TS* records in the DSS file using *HEC-DSSVue*. These *TS* record monthly instream flow targets representing SB3 environmental flow standards developed in a daily simulation are read as input in the monthly simulation.

SIMD also provides comprehensive capabilities for simulating reservoir flood control operations. Any number of reservoirs with flood control pools can be operated either individually or as multiple-reservoir systems to control flooding at any number of downstream control points. Uncontrolled surcharge reservoir releases can also be included in the simulation.

The HEC Data Storage System (DSS) and its *HEC-DSSVue* interface are particularly useful in the WRAP daily modeling system. DSS is designed for efficiently managing time series data, including extremely large datasets. The *SIMD* daily simulation input and output include extremely large time series that are very well suited for DSS and *HEC-DSSVue*.

A daily WRAP modeling system case study of the Brazos River Basin supported the initial development of the daily modeling capabilities [27, 44]. Several other unpublished technical reports document monthly and daily WRAP simulation studies performed in conjunction with TCEQ sponsored research and development at TAMU that further contributed to development of the daily WRAP modeling system and expanding capabilities for integrating environmental flow standards in comprehensive water resources management.

CHAPTER 7

PROGRAM TABLES ANALYSES OF SIMULATION INPUT AND RESULTS

The primary role of the WRAP program *TABLES* is to convert extensive time series of simulation results output data into meaningful information. An array of routines are provided for organizing, analyzing, summarizing, and displaying simulation results. *TABLES* also includes options for tabulating and analyzing simulation input data from a *SIMSIMD* input DAT file. *TABLES* reads *SIM/SIMD* input and output files or any DSS file, computes reliability and frequency metrics, performs various other data manipulations, and develops a variety of tables and data tabulations. *TABLES* also provides capabilities for converting simulation results into formats that facilitate further organization and analysis with *HEC-DSSVue* and *Microsoft Excel*. Computational methods and the format and interpretation of the tables created by *TABLES* are outlined in this chapter. Chapter 5 of the *Users Manual* provides instructions for employing *TABLES*, which should be viewed by the reader concurrently with reading this chapter.

Programs *SIM* and *TABLES* and their combined application are addressed in this *Reference Manual* and companion *Users Manual* and the *Fundamentals Manual*. *TABLES* also provides similar capabilities for organizing, analyzing, summarizing, and displaying programs *SIMD* and *SALT* simulation results which are covered in the *Daily Manual and Salinity Manual*.

Types of Tables Created with *TABLES*

The *TABLES* input TIN file specifies the tables and/or other types of information to be created and written to the *TABLES* output TOU file. The TIN file input records begin with the four-character identifiers shown in parenthesis in Table 7.1. Each record activates routines that create sets of tables or tabulations in a variety of user-specified formats.

Chapter 5 of the *Users Manual* explains *TABLES* types 1, 2, 3, 4, 5, 6, and 7 input records. The *Salinity Manual* provides instructions for applying *TABLES* type 8 records. Conditional reliability modeling (CRM) is covered in Chapter 8 of this manual. The present *Reference Manual* Chapter 7 covers essentially all of the *TABLES* routines from the perspectives of their conceptual basis and the computational methods employed.

Type 1 input records activate routines that read the main *SIM* input DAT file and organize selected data as described in this chapter. The 1REC routine simply lists *SIM* input records of user-selected types. The 1RCT record counts the number of each type of record found in the DAT file. A 1SRT record creates a listing of water rights sorted in priority order or a listing by type of use, control point, water right type, or water right group in priority order with selected information. The 1SUM record instructs *TABLES* to create water right summary tables organized in user-selected formats. The 1RES record provides information about reservoirs. The 1CPT record provides options for rearranging control point records in upstream-to-downstream order and developing listings of control points with user-specified information.

Basic concepts of type 2 routines are the main focus of this chapter. Type 2 routines provide an array of options for organizing, analyzing, and displaying *SIM* simulation results. Most of the types 6, 7, and 8 options are analogous to type 2 features. DSSM, DSSD, and 7DSS records allow application of the main analyses capabilities to any data from any DSS file.

Table 7.1
Outline of Program *TABLES* Features

TABLES Input Records Covered in Chapter 5 of the *Users Manual*

Auxiliary: IDEN, DSSM, DSSD, DATA, PAGE, TITL, TEST, FILE, UNIT, ENDF

Type 1: Tables developed from *SIM* input DAT file (1REC, 1RCT, 1SRT, 1SUM, 1RES, and 1CPT).

Type 2: Tables developed from *SIM* output OUT file (or DSS file).

- Time series tables (input records identifiers listed in Table 5.1)
- Reliability and frequency tables (2REL, 2FRE, 2FRQ, 2RES, DSSM)
- Summary tables (2SCP, 2SWR, 2SRE, 2SGP, 2SBA)
- Water budget tables (2BUD)

Type 3: *SIM* input records developed from *SIM* output OUT file (3REG, 3NAT, 3UNA, 3DEP, 3U+D, 3EPD).

Type 4: Tables from *SIM* hydropower and reservoir release HRR file (4HRR) and *SIM* priority sequence flow availability ZZZ file (4ZZZ and 4ZZF).

Type 5: Conditional reliability modeling tables developed from *SIM* or *SIMD* CRM file as discussed in Chapter 8 (5CRM, 5CR1, 5CR2, 5COR).

Type 6: Daily time step time series, reliability, and frequency tables from *SIMD* SUB file or DSS file (type 6 version of time series records listed in Table 5.1, 6REL, 6FRE, 6FRQ, 6RES, DSSD).

Type 7: Frequency analysis table of annual series developed from any DSS file (7DSS). Flood frequency analyses table developed from *SIMD* output AFF file (7FFA).

TABLES Input Records Covered in the *Salinity Manual*

Type 8: Tables of salinity simulation results from *SALT* SAL file (8SAL, 8FRE, 8FRQ, 8SUM, 8REL, 8CON).

Type 3 records are designed to convert time sequences of naturalized flows, regulated flows, unappropriated flows, and/or stream flow depletions read from a *SIM* OUT file into the format of *IN* or *TS* records that can be incorporated into a *SIM* input DAT file. Similar more comprehensive capabilities for converting *SIM* simulation results to *SIM* input records are contained in program *HYD*. HEC-DSSVue can serve the same purpose using DSS records. These features address modeling applications in which results from a *SIM* simulation reflecting a certain water management scenario are incorporated into the input of other *SIM* simulations.

Type 4 records develop tables from *SIM* HRR and ZZZ output files which are discussed in Chapter 6 of this manual. The primary purpose of the HRR file is comparison of releases from the individual reservoirs of a multiple-reservoir system and also hydropower production associated with individual water rights. Monthly or annual tables of hydropower targets, hydropower production, and releases from all system reservoirs associated with system water rights with the

TABLES 4HRR record. The *SIM* ZZZ output file and associated *TABLES* 4ZZZ and 4ZZF input records provide capabilities described in Chapter 6 for tracking the effects of each individual water right in the priority sequence on stream flows at specified control points.

SIM and *TABLES* conditional reliability modeling (CRM) covered in Chapter 8 includes *TABLES* routines activated by type 5 records. The conceptual basis and computational methods of the type 5 record routines are covered in Chapter 8. The *TABLES* type 5 records employed in CRM are also covered in Chapter 5 of the *Users Manual*.

The types 6, 7, and 8 *TABLES* input records are described in the *Daily* and *Salinity Manuals*. The conceptual basis and computational methods employed in all of the reliability and frequency analyses are covered in the present Chapter 7 of this *Reference Manual*.

Example in the Fundamentals Manual

The *Fundamental Manual* focuses on an example that illustrates application of *SIM* and *TABLES* in a conventional manner to assess water availability for a river/river system. The other WRAP manuals build upon and expand the example from the *Fundamentals Manual* to employ additional modeling features covered in the various chapters of the particular manual. The *Fundamentals Manual* example is adopted in this chapter of this manual to support a discussion of the modeling and analysis methodologies implemented in the WRAP program *TABLES*.

The hypothetical river/reservoir/use system water availability model (WAM) described in detail in the *Fundamentals Manual* includes 11 control points, 6 reservoirs, 2 *IF* record instream flow rights, and 28 *WR* record water rights. One of the water rights includes generation of hydroelectric energy. Most include water supply. The hydrologic period-of-analysis extends from January 1940 through December 2016. The simulation is performed with a computational time step of one month.

Programs *SIM* and *TABLES* and their combined use are covered in the *Fundamentals Manual*. The *SIM* input DAT, FLO, and EVA files and simulation results output OUT file described in the *Fundamentals Manual* are adopted here without change but are not discussed further in this chapter. The present chapter focuses on using *TABLES* to organize and analyze the simulation results read by *TABLES* from the *SIM* output OUT file.

Summary Analyses of Water Rights Information in the Simulation Input Datasets

The six type 1 input records described in the *Users Manual* begin with the record identifiers 1REC, 1RCT, 1SRT, 1SUM, 1RES, and 1CPT. The purpose of the *TABLES* routines activated by these TIN file input records is to summarize and organize selected input data from the *SIM* input DAT file. The 1REC feature simply allows *SIM* input records of any record type to be copied to the *TABLES* output TOU file. The 1RCT counts the number of records of each of the 58 types of records possible in a *SIM* input DAT file and 17 additional record types possible in a *SIMD* DAT file. The following discussion along with Tables 7.2, 7.3, 7.4, 7.5, and 7.6 describe the routines controlled by the 1SRT, 1SUM, 1RES, and 1CPT records. 1SRT, 1SUM, and 1RES records access information regarding water rights and their associated reservoirs. The 1CPT record deals with control points.

A *TABLES* input TIN file is reproduced as Table 7.2. The resulting *TABLES* output file is subdivided as Tables 7.3, 7.4, 7.5, and 7.6 which reproduce the tables created with the 1SRT, 1SUM, 1RES, and 1CPT records, respectively. *TABLES* developed these tables from the data read from the *SIM* input DAT file reproduced and discussed in the *Fundamentals Manual*. However, type 1 tables are not included in the necessarily limited set of tables selected for presentation in the *Fundamentals Manual*.

Table 7.2
TABLES Input TIN File with Type 1 Records

1SRT	3	
1SUM	3	
1RES		
1CPT	7	Belton
ENDF		

The 1SRT record allows the user to list all water rights in priority order without grouping or to categorize the water rights into groups and list the water rights within each group in priority order. The groups may be defined optionally by control point (*WR* or *IF* record field 2), type of use (*WR* or *IF* record field 4), water right type (*WR* or *IF* record field 6), or by the group identifiers in *WR* record fields 13 and 14 or *IF* record fields 12 and 13. The entry 3 in the second field of the 1SRT record of Table 7.2 results in the 30 water rights in the DAT file being grouped by water use types IND1, IND2, IRR2, MUN1, MUN2, POWER, and NDAYS. Water rights WR-5, WR-25, WR-26, WR-27, and WR-28 with blank use type fields on their *WR* records are grouped together. Water rights IF-1 and IF-2 with use type NDAYS are also treated as a group. Within each group, the water rights are listed in priority order.

1SRT tables are comprised of the following columns which are illustrated in Table 7.3. The 1SRT record also allows an alternative table format, not shown here, with some of these columns omitted.

1. Water right identifier WRID(wr) from *WR* record field 12 or *IF* record field 11.
2. Water right type (1, 2, 3, 4, 5, 6, 7, or 8) from *WR* record field 6. Since instream flow *IF* record water rights do not have this right type parameter, the integer 9 is adopted for the type column of the 1SRT table to label *IF* record rights.
3. Priority number from *WR* or *IF* record field 5.
4. Authorized annual diversion or instream flow amount from *WR* or *IF* record field 3.
5. Annual electric energy generation target from *WR* record field 3 for hydropower rights.
6. Identifier of primary reservoir refilled by the water right from *WS* record field 2.
7. Storage capacity to which the water right fills the reservoir from *WS* record field 3.
8. Inactive storage volume from *WS* record field 7.
9. Number of secondary reservoirs that release to supply the water right.
10. Total capacity of the secondary reservoirs from field 2 of one or more *WS* records.
11. First water right group identifier from *WR* record field 13 or *IF* record field 12.
12. Second water right group identifier from *WR* record field 14 or *IF* record field 13.

As indicated by Table 1.2 in Chapter 1, the twenty TCEQ WAM System datasets for the 15 major river basins and eight coastal basins of Texas include a total of over 10,000 *WR* and *IF* record water rights. The DAT files for the larger WAMs include many hundreds of water rights.

The 1SRT tables are very long if all of the water rights are included. Likewise, other types of tables discussed later in this chapter may be extremely long if all water rights are included. Options are provided by the 1SRT record and other *TABLES* input records discussed later to limit the water rights included in a table to a user-defined subset instead of including all rights.

Table 7.3
1SRT Priority Sorted Water Rights by Selected Category

WATER RIGHTS INPUT DATA IN PRIORITY ORDER SORTED BY USE
The DAT file contains 28 WR records and 2 IF records. Only water rights meeting the criteria on the 1SRT record are included in the following table.

WATER RIGHT IDENTIFIER	WR TYPE	PRIORITY	CP	USE	AUTHORIZED AMOUNT (AC-FT/YR)	HYDRO POWER ! (MW-HR)	!+++PRIMARY ID	RESERVOIR TOTAL (AC-FT)	!-SECONDARY-! INACTIVE NUM (AC-FT)	ACTIVE ! (AC-FT)	GROUP WRIDS (1)	IDENTIFIERS WRIDS (2)
WR-2	1	193804	FK	IND1	245000.0	0.	FK	570240.0	0.0	0	0.	FK
WR-9	1	196312	Belton	IND1	97500.0	0.	Belton	457600.0	0.0	0	0.	Belton
WR-13	1	196105	Camer	IND2	18200.0	0.		0.0	0.0	0	0.	Cameron
WR-19	1	196105	Bryan	IND2	39000.0	0.		0.0	0.0	0	0.	Bryan
WR-21	1	196105	Hemp	IND2	95600.0	0.		0.0	0.0	0	0.	Hemp
WR-14	1	194510	Camer	IRR2	11300.0	0.		0.0	0.0	0	0.	Cameron
WR-20	1	194510	Bryan	IRR2	34500.0	0.		0.0	0.0	0	0.	Bryan
WR-22	1	194510	Hemp	IRR2	49600.0	0.		0.0	0.0	0	0.	Hemp
WR-16	1	194607	WacoG	IRR2	32300.0	0.		0.0	0.0	0	0.	WacoGage
WR-17	1	195903	High	IRR2	44800.0	0.		0.0	0.0	0	0.	Highbank
WR-12	1	198211	Camer	IRR2	92100.0	0.		0.0	0.0	0	0.	Cameron
WR-23	1	200601	Hemp	IRR2	74500.0	0.		0.0	0.0	0	0.	Hemp
WR-6	1	192901	WacoL	MUN1	60000.0	0.	WacoL	104100.0	0.0	0	0.	WacoLake
WR-1	1	193804	FK	MUN1	9800.0	0.	FK	570240.0	0.0	0	0.	FK
WR-8	1	196312	Belton	MUN1	82760.0	0.	Belton	457600.0	0.0	0	0.	Belton
WR-3	1	198208	Whit	MUN1	18000.0	0.	Whit	627100.0	379000.0	0	0.	Whitney
WR-7	1	198609	WacoL	MUN1	20800.0	0.	WacoL	192100.0	0.0	0	0.	WacoLake
WR-10	1	196802	George	MUN2	25610.0	0.	George	37100.0	0.0	0	0.	George
WR-11	1	196802	Grang	MUN2	42000.0	0.	Grang	65500.0	0.0	0	0.	Granger
WR-18	1	198211	Bryan	MUN2	25400.0	0.		0.0	0.0	0	0.	Bryan
WR-15	2	200601	Camer	MUN2	88000.0	0.		0.0	0.0	3	560200.	SystemC
WR-24	2	200601	Hemp	MUN2	900000.0	0.		0.0	0.0	4	1130440.	SystemH
WR-4	6	888888	Whit	POWER	0.0	36000.		0.0	0.0	1	248100.	Whit HP
WR-5	1	999999	Whit		0.0	0.	Whit	627100.0	379000.0	0	0.	Refill
WR-25	1	999999	FK		0.0	0.	FK	570240.0	0.0	0	0.	Refill
WR-26	1	999999	Belton		0.0	0.	Belton	457600.0	0.0	0	0.	Refill
WR-27	1	999999	George		0.0	0.	George	37100.0	0.0	0	0.	Refill
WR-28	1	999999	Grang		0.0	0.	Grang	65500.0	0.0	0	0.	Refill
IF-1	9	0	Camer	NDAYS	3600.0	0.		0.0	0.0	0	0.	
IF-2	9	0	Hemp	NDAYS	120000.0	0.		0.0	0.0	0	0.	

30 water rights are included in the table.

Switch parameters WRIF, HEP, ART, XAMT, XPS, XPS, XUSE, and XGROUP in fields 3-10 of the 1SRT record are not employed in the example of Tables 7.2 and 7.3. These parameters allow defined subgroups of water rights to be included in the 1SRT table. Any or all of these

parameters may be activated. A water right must fall within the criteria of each and all of the activated parameters in order to be included in the table. The same sub-set defining parameters are employed by the 1SUM record and some are included on the 2REL record. These 1SRT, 1SUM, and 2REL record parameters defined the following subsets of water rights.

WRIF (1) Both *WR* and *IF* record rights. (2) Only *WR* record rights. (3) Only *IF* record rights.

HEP (1) No limit default. (2) Hydropower rights excluded. (2) Only hydropower are included.

ART (1) No limit default. (2) Artificial rights are excluded. (2) Only artificial rights included.

XAMT Lower limit on annual diversion or instream flow target from *WR/IF* record field 3.

XPS Priority number must be less than (senior to) XPS.

XPJ Priority number must be greater than (junior to) XPJ.

XUSE USE from *WR/IF* record field 3 must be XUSE.

XGROUP Either first or second water right group identifier must be XGROUP.

Any, all, or none of these criteria are applied depending on the entries for the parameters listed above. A water right is excluded from the table if one or more of the activated criteria are not satisfied. None of these criteria are activated in the files shown in Tables 7.2 and 7.3.

These same sub-set defining criteria are employed by non-blank entries for WRIF, HEP, ART, XAMT, XPS, XPS, XUSE, and XGROUP in fields 3-10 of the 1SUM record. These fields are blank in both the 1SUM and 1SRT records in Table 7.2.

The 1SUM record routine uses the same data read from the *SIM* input DAT file as the 1SRT record but sums the quantities by defined group rather than listing each individual water right in the table. The same groups can be specified by the parameter KK in field 2 of both the 1SUM and 1SRT records. Option 3 meaning use type is selected in this example. The "blank" in the first column represents those rights that have blank use fields in their *WR* or *IF* record. A summary by use type is shown in Table 7.4. The first column can be changed from use to either control point, water right type, or group identifier. The 1SUM routine can also sum the data by control point but include only the totals in the table, reducing the table to the final TOTALS line shown in Table 7.4.

Multiple water rights can share the same reservoir. A water right may have multiple reservoirs. Thus, storage volumes may be double-counted in summing the reservoir storage column of the 1SUM table. Therefore, the bottom totals line excludes reservoir storage unless the control point KK option is selected. The 1SUM sums storage at all of the control points included in the table to obtain a correct bottom-line total without double-counting.

The 1RES record in the TIN file of Table 7.2 creates the TOU file 1RES table presented as Table 7.5. Each line in the 1RES record table represents a *WS* record read from the DAT file. All reservoir storage *WS* records must follow either a *WR* or *IF* record, usually a *WR* record. The information in a 1RES record is derived from *WS* records and the water right *WR* or *IF* records that they support. As illustrated by Table 7.5, multiple water rights can share the same reservoir, with each water right having its own *WS* record and line in the 1RES table. The *WS* records (lines of data) are grouped by reservoir in the 1RES table, but each reservoir may occupy any number of lines in the table.

Table 7.4
1SUM Water Rights Summary

WATER RIGHTS INPUT DATA SUMMARY BY USE

The DAT file contains 28 WR records and 2 IF records. Only water rights meeting the criteria on the 1SUM record are included in the following table.

USE	NUMBER	ANNUAL	NUMBER	RESERVOIR	PRIORITIES	
	OF RIGHTS	AMOUNT (AC-FT/YR)	OF RESERVOIRS	STORAGE (AC-FT)	FROM	TO
IND1	2	342500.	2	1027840.	193804	196312
IND2	3	152800.	3	0.	196105	196105
IRR2	7	339100.	7	0.	194510	200601
MUN1	5	191360.	5	1951140.	192901	198609
MUN2	5	1081010.	5	102600.	196802	200601
POWER	1	0.	1	0.	888888	888888
	5	0.	5	1757540.	999999	999999
NDAYS	2	123600.	2	0.	0	0
TOTALS	30	2230370.	---	---	0	999999

Table 7.5
1RES Reservoir Information

RESERVOIR INFORMATION COMPILED WITH 1RES RECORD

Each line in the table represents a WS record. The data were read from each WS record and its preceding WR or IF record.

The DAT file contains 22 WS records representing 6 reservoirs.

Reservoir	Storage Capacity	Inactive Storage	Water Right	Control Point	WR Priority	Type
PK	570240.0	0.0	WR-1	PK	193804	0
PK	570240.0	0.0	WR-2	PK	193804	0
PK	570240.0	0.0	WR-24	Hemp	200601	2
PK	570240.0	0.0	WR-25	PK	999999	0
Whit	627100.0	379000.0	WR-3	Whit	198208	0
Whit	627100.0	379000.0	WR-4	Whit	888888	6
Whit	627100.0	379000.0	WR-5	Whit	999999	0
WacoL	104100.0	0.0	WR-6	WacoL	192901	0
WacoL	192100.0	0.0	WR-7	WacoL	198609	0
Belton	457600.0	0.0	WR-8	Belton	196312	0
Belton	457600.0	0.0	WR-9	Belton	196312	0
Belton	457600.0	0.0	WR-15	Camer	200601	2
Belton	457600.0	0.0	WR-24	Hemp	200601	2
Belton	457600.0	0.0	WR-26	Belton	999999	0
George	37100.0	0.0	WR-10	George	196802	0
George	37100.0	0.0	WR-15	Camer	200601	2
George	37100.0	0.0	WR-24	Hemp	200601	2
George	37100.0	0.0	WR-27	George	999999	0
Grang	65500.0	0.0	WR-11	Grang	196802	0
Grang	65500.0	0.0	WR-15	Camer	200601	2
Grang	65500.0	0.0	WR-24	Hemp	200601	2
Grang	65500.0	0.0	WR-28	Grang	999999	0

Number of WS records included in the tabulation = 22
 Number of reservoirs included in the tabulation = 6
 Total storage capacity (acre-feet) = 1949640.0
 Number of reservoirs included in the DAT file = 6
 Total storage capacity (acre-feet) = 1949640.0

The 1RES table has the following columns.

- reservoir identifier from *WS* record field 2
- storage capacity to which the water right fills the reservoir from *WS* field 3
- inactive storage capacity from *WS* record field 7
- water right identifier from *WR* record field 12 or *IF* record field 11
- control point identifier from *WR/IF* record field 2
- water right priority from *WR/IF* record field 5
- water right type from *WR* record field 5 or numeral 9 for *IF* record rights

XLIMIT with a default of 0.0 is the only input parameter on the 1RES record. Only reservoirs with storage capacities exceeding XLIMIT are included in the 1RES table. As indicated in Table 1.2 several of the WAMs have hundreds of reservoirs. Most of the storage capacity is contained in a relatively small number of the largest reservoirs. XLIMIT is designed to control the length of the 1RES table by excluding the numerous smaller reservoirs.

Control point *CP* records can be entered in the DAT file in any order. The 1CPT record activates a routine that sequences the control points in upstream-to-downstream order. Two alternative schemes selected by the order option OO parameter described in the *Users Manual* reflect differences in the details of the upstream-to-down sequencing. The parameter KK allows selection of various information to be included in the 1CPT table created in the TOU file. KK option 7 selected on the 1CPT record of Table 7.2 provides the information on the TOU file table reproduced as Table 7.6.

Table 7.6
1CPT Upstream-to-Downstream Sequencing of Control Points

1CPT Record KK Option 7			
CP, Channel Loss Factor, Delivery Factor, and Cumulative Delivery Factor from CP Belton			
Belton	0.02800	0.97200	1.00000
Camer	0.03600	0.96400	0.97200
Bryan	0.02500	0.97500	0.93701
Hemp	0.00000	1.00000	0.91358

Control point Belton and all control points located downstream of control point Belton are listed in the 1CPT table of Table 7.6 in upstream-to-downstream order. Control point Hemp is the outlet of the river system (most downstream control point). The four columns of the table provide the following information.

- control point identifier from *CP* record field 2
- channel loss factor (L) from *CP* record field 10
- delivery factor (D) computed as $D = 1.0 - L$
- cumulative delivery factor computed as the product of a sequence of delivery factors

The cumulative delivery factor for control point Hemp is computed by *TABLES* as:

$$(1.0 - 0.028)(1.0 - 0.036)(1.0 - 0.025) = 0.91358$$

Streamflow depletions and return flows are propagated downstream in the *SIM* simulation. A streamflow depletion is defined as the volume of water appropriated to meet a diversion target or refill reservoir storage. The channel loss factor of 0.028 at control point Belton is the fraction by which a streamflow depletion or return flow at control point Belton is reduced to determine the adjustment in flow at control point Camer. The adjustment to streamflow at Camer is computed in the *SIM* simulation by multiplying the streamflow depletion or return flow at Belton by the cumulative delivery factor of 0.972. The adjustment to streamflow at control point Hemp is computed in the *SIM* simulation by multiplying the streamflow depletion or return flow at Belton by the cumulative delivery factor of 0.91358.

The 1CPT routine will typically be applied to develop tables of information stored in the *TABLES* output TOU file that provide insight in understanding the WAM applied in a simulation study. However, 1CPT KK option 8 creates an array defining the upstream-to-downstream sequencing of control points that is stored in computer memory but not recorded in the TOU file. This array is designed for use with the 2BUD record in developing water budget tables.

The upstream-to-downstream sequencing of *CP* records is also required for a WRAP-*SALT* salinity simulation. KK option 1 is employed to reproduce the *CP* records in upstream-to-downstream order in the TOU file. The rearranged *CP* records are then inserted into the DAT file used in the salinity tracking simulation.

DATA Record Transformation of Simulation Results Data

The DATA record converts *SIM* or *SIMD* simulation results to other related datasets that can be read by the time series and frequency records described in the following sections of this chapter. All of the simulation results time series variables from the *SIM* OUT or *SIMD* SUB output files listed in Table 5.1 can be read with a DATA record and manipulated to create other datasets consisting of daily or monthly quantities or annual totals, minima, or maxima covering a specified number of time periods defining a season of the year. The new dataset can be read and organized by time series records just like the original variables listed in Table 5.1. Time series record identifiers are listed in column 2 of Table 5.1. The DATA record also allows 2FRE and 2FRQ record frequency analyses to be performed for all of the variables listed in Table 5.1 and other adjusted datasets derived from the variables listed in Table 5.1.

The sole purpose of the DATA record is to transform *SIM* or *SIMD* simulation results to other time series variables of interest to be accessed as input by *TABLES* time series and/or frequency analysis record routines. Although the DATA record has broad general applicability, environmental instream flow studies based on daily *SIMD* simulation results provide a key motivation for its design. The *Daily Manual* describes the daily (type 6) equivalents of the *TABLES* time series records listed in Table 6.1 and the daily 6FRE and 6FRQ record versions of the monthly 2FRE and 2FRQ frequency analysis records. Determining annual exceedance probabilities for the minimum 7-day volume of naturalized or regulated stream flow is an example of combining the DATA and frequency records with *SIMD* daily simulation results.

The 37 *TABLES* time series record identifiers listed in Table 5.1 represent 31 monthly time series variables read directly from the *SIM* output OUT file and 6 other variables computed by combining simulation result variables. The variables are associated with either control points,

water rights, or reservoirs. Several of the water right variables are also aggregated by control point or reservoir in the *SIM* simulation results.

All of these variables have daily equivalents recorded in the *SIMD* output SUB file discussed in the *Daily Manual*. Examples in the *Daily Manual* illustrate the use of the DATA record with daily data. The time series records with identifiers listed in the second column of Table 5.1 can be applied directly with all 37 variables without using a DATA record. 2FRE and 2FRQ record frequency analyses can be performed directly without a DATA record with nine of the 37 variables. The *TABLES* routines activated by the DATA record work with any of the 37 variables and develop other transformed datasets that are not otherwise available to the time series and frequency records.

Any number of DATA records may be included in a *TABLES* input TIN file. Any number of time series and/or frequency records may use datasets created by each DATA record.

The DATA record performs the following tasks in the sequential order listed below.

Step 1: *SIM* monthly or *SIMD* daily simulation results are read from an OUT or SUB file. Only data that falls within the season (months) specified on the DATA record are read.

Step 2: The following equation with factors *XF* and *AF* from the DATA record, with defaults of $XF=1.0$ and $AF=0.0$, converts the original data series *X1* to a new series *X2*.

$$X2 = (XF)(X1) + AF$$

Step 3: Optionally, either moving averages or moving totals of the quantities at the completion of step 2 in the current and preceding specified number of time steps (months for *SIM* or days for *SIMD*) may be computed.

Task 4: Optionally, the monthly or daily dataset at the completion of step 3 may be converted to an annual series consisting of either the total, minimum, or maximum for each year.

Task 5: The resulting annual data array and/or monthly (*SIM*) or daily (*SIMD*) data array are stored in memory for subsequent use by time series and/or frequency analysis records. Thus, the final product of a DATA record is either one or two datasets (annual and/or monthly/daily) stored in computer memory as arrays.

Task 6: An option allows the arrays to be written to the message file for general information.

Data are read and manipulated for only the months in the specified season, which may range from one to 12 months. The default season is the entire year (months 1-12). In creating an annual series, the year is always defined as months 1 through 12 which are typically though not necessarily January through December. The season specified on the DATA record may fall within a single year or may encompass parts of two years. For example, a 4-month long season defined as months 5 through 8 (May-October) falls totally within the year. A 4-month season defined as months 11 through 2 (November through February) is split between years.

The DATA options listed above as steps 2 and 3 are also options in the time series and frequency records. The computations are identical with either of the record types. The steps 2 and 3 options can be applied to the original simulation results by a DATA record and then to the

resulting dataset by time series or frequency records. Moving totals are the summation of amounts for a specified number of time steps (months or days) that include the current and preceding time steps. Moving averages are moving totals summed over the specified number of time steps divided by the number of time steps.

Example of Applying the DATA Record

The TABLES output TOU file reproduced as Table 7.7 is created from SIM simulation results using the following TABLES input TIN file consisting of a DATA record followed by two 2FRE records presenting frequency analysis results in two different formats.

```

DATA2REG    0    0    0    0    0    0    6    0    8
2FRE  11    0    0    2                0.005480
2FRE  11    0    0    1                0.005480
ENDF

```

The example consists of estimating the frequency (probability or likelihood) of the mean regulated flow during the summer months of June through August either exceeding or falling below various levels at eleven control points. The DATA record reads the monthly regulated flows at 11 control points from the SIM output OUT file. The regulated flows in June, July, and August in each of 77 years are summed to develop a 77-year annual series of 3-month regulated flow volumes in acre-feet.

Although performing a frequency analysis of flows in units of acre-feet is fine, the units are converted to cubic feet per second (cfs) in this example by applying the multiplier factor 0.005480 entered on the 2FRE record. This optional unit conversion factor is calculated as:

$$(\text{acre-feet}/92 \text{ days}) (43,560 \text{ acre-feet}/\text{cubic foot}) (\text{day}/86,400 \text{ seconds}) = 0.005480$$

Thus, the frequency analysis is performed for the mean summer (June-August) regulated stream flow in units of cfs. The frequency analysis results are presented in Table 7.7.

The 75% exceedance frequency mean summer flow at control point PK is 276.99 cfs. Based on the 3-month June-July mean flow at PK equaling or exceeding 277 cfs during 75% of the 58 years of the simulation, the probability that the mean flow during any summer will be less than 277 cfs is estimated to be 25%. The median (50% exceedance frequency) mean flow during June through July is 760 cfs at control point PK and 882 cfs at control point Hemp.

Two alternative format options for 2FRE tables are compared in Table 8.6. As discussed later in this chapter, the 2FRE and 2FRQ records provide various alternative computational methods. The computation options are applied to datasets created with a DATA record in the same manner as to the original simulation results read directly from the SIM output file.

Another example of a derived variable consists of applying the DATA record moving total option with the default January through December season specified to develop an annual series of a variable defined as the minimum 3-month flow volume each year regardless of season. The DATA record provides flexibility in defining a variety of variables and developing annual, monthly, or daily datasets for these variables derived from simulation results.

Table 7.7
TABLES Output TOU File for DATA Record Example

VARIABLE 2REG IN DATA RECORD DATASET

DATA Record Parameters DR(1-10) 0 0 1 0 0 1 6 1 8 99

CP	FK	Whit	WacoL	WacoG	High	Belton	George	Grang	Camer	Bryan	Hemp
Mean	1064.00	1421.95	209.86	1988.84	2208.19	482.55	79.16	258.48	1069.48	3601.91	2897.01
Std Dev	1066.75	1347.09	269.63	1507.38	1729.61	453.28	108.49	294.47	1083.82	2739.15	3579.25
Minimum	0.00	0.00	0.00	73.57	17.05	0.00	0.00	0.00	4.97	3.90	165.75
99.5%	0.00	0.00	0.00	138.01	82.24	0.00	0.00	0.00	4.97	146.69	165.75
99%	0.00	0.00	0.00	202.45	147.42	0.00	0.00	0.00	4.97	289.48	165.75
98%	0.00	0.00	0.00	347.01	305.51	0.00	0.00	0.00	4.97	610.91	165.75
95%	0.00	0.00	0.00	618.05	644.33	0.00	0.00	0.00	4.97	1270.43	165.75
90%	0.00	82.08	0.00	718.18	780.71	1.18	0.00	1.04	43.25	1490.97	165.75
85%	66.71	261.77	0.00	815.87	849.72	35.90	0.00	3.17	63.64	1651.21	165.75
80%	132.66	399.06	0.00	888.98	904.86	52.64	0.00	6.98	169.22	1709.06	165.75
75%	276.99	599.05	0.00	986.78	973.72	62.97	0.29	24.27	295.35	1737.25	165.75
70%	458.97	680.28	1.65	1033.86	1064.62	108.36	0.68	52.93	373.57	1825.65	197.83
60%	622.64	844.80	46.73	1401.36	1425.35	206.35	3.03	76.94	598.64	1911.41	431.48
50%	759.86	1219.59	107.10	1544.47	1587.38	348.27	27.95	159.10	853.39	2160.28	882.19
40%	1050.76	1435.31	143.37	1755.62	1874.70	594.46	53.01	302.42	990.91	3372.74	2941.22
30%	1450.35	1597.52	310.47	2129.00	2662.31	794.03	84.14	386.51	1254.10	4456.94	4356.33
25%	1527.02	1771.73	396.46	2470.52	2808.75	875.57	131.30	403.52	1550.02	5270.70	4731.28
20%	1645.33	2154.05	447.03	3094.67	3680.72	925.60	205.78	430.44	1845.96	6116.38	5578.34
15%	1836.09	2629.88	551.58	3723.21	4096.70	1060.56	221.84	492.98	2195.83	6848.11	6908.87
10%	2758.59	3094.91	688.44	3891.32	4869.90	1249.25	257.24	636.15	2617.88	7700.67	8645.40
5%	3474.63	4472.02	816.20	5192.05	5803.72	1331.01	315.00	914.60	3703.36	9219.68	10998.34
2%	4785.12	6510.57	947.25	7249.09	8068.40	1450.27	392.47	1338.14	4759.87	12281.09	14026.07
1%	4876.21	6617.10	968.61	7264.36	8218.37	1450.98	401.44	1362.08	4879.57	12392.87	14136.72
0.5%	4876.21	6617.10	968.61	7264.36	8218.37	1450.98	401.44	1362.08	4879.57	12392.87	14136.72
Maximum	4876.21	6617.10	968.61	7264.36	8218.37	1450.98	401.44	1362.08	4879.57	12392.87	14136.72

VARIABLE 2REG IN DATA RECORD DATASET

DATA Record Parameters DR(1-10) 0 0 1 0 0 1 6 1 8 99

CONTROL POINT	STANDARD		PERCENTAGE OF YEARS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
FK	1064.0	1067.	0.0	0.0	0.0	0.0	0.0	277.0	623.	760.	1051.	1527.	2759.	4876.
Whit	1421.9	1347.	0.0	0.0	0.0	0.0	82.1	599.1	845.	1220.	1435.	1772.	3095.	6617.
WacoL	209.9	270.	0.0	0.0	0.0	0.0	0.0	0.0	47.	107.	143.	396.	688.	969.
WacoG	1988.8	1507.	73.6	202.5	347.0	618.0	718.2	986.8	1401.	1544.	1756.	2471.	3891.	7264.
High	2208.2	1730.	17.0	147.4	305.5	644.3	780.7	973.7	1425.	1587.	1875.	2809.	4870.	8218.
Belton	482.5	453.	0.0	0.0	0.0	0.0	1.2	63.0	206.	348.	594.	876.	1249.	1451.
George	79.2	108.	0.0	0.0	0.0	0.0	0.0	0.3	3.	28.	53.	131.	257.	401.
Grang	258.5	294.	0.0	0.0	0.0	0.0	1.0	24.3	77.	159.	302.	404.	636.	1362.
Camer	1069.5	1084.	5.0	5.0	5.0	5.0	43.2	295.3	599.	853.	991.	1550.	2618.	4880.
Bryan	3601.9	2739.	3.9	289.5	610.9	1270.4	1491.0	1737.3	1911.	2160.	3373.	5271.	7701.	12393.
Hemp	2897.0	3579.	165.8	165.8	165.8	165.8	165.8	165.8	431.	882.	2941.	4731.	8645.	14137.

Time Series Tables and Tabulations

The time series data from a *SIM* simulation results OUT file or DATA record array are written by *TABLES* to the tables in the *TABLES* output TOU file and/or as records to a DSS file as specified by input records with the identifiers listed in the second column of Table 5.1. Optionally, moving averages or moving accumulative totals of the data for a user-specified number of months may be computed and written to the TOU file and/or the DSS file. The data may also be adjusted by a multiplier factor, such as unit conversion factors, or subtracted from a given constant, such as computing reservoir drawdown as capacity minus storage content.

The original *SIM* monthly simulation results, aggregated annual totals, or computed moving averages, moving totals, or otherwise adjusted time series data may be organized by *TABLES* in the following formats.

- A text file with the filename extension TOU has each time series organized as a separate table with annual rows and monthly columns with headings illustrated by Table 7.8. The variables in Table 5.1 are presented as a set of separate tables for each selected water right, control point, or reservoir/hydropower project. This format is designed for report preparation and convenient viewing of simulation results.
- Each variable of interest may be tabulated as one column of a table written to the TOU file along with the tables described above. Either monthly simulation results or annual totals may be tabulated. A monthly table would be 12 times longer than the table of annual totals shown in Table 7.9. Any of the variables and any water right, control point, or reservoir/hydropower project may be selected for inclusion in the up to 100 column tabulation. This format is designed for convenient transport to Microsoft Excel or other spreadsheet programs.
- A binary file with the filename extension DSS has each time series variable of interest stored as a HEC-DSS record. This format is designed to allow the data to be read by HEC-DSSVue for plotting or further computations. Monthly or annual time series of any of the variables listed in Table 5.1 may be converted by *TABLES* to DSS records and plotted with HEC-DSSVue as illustrated by Figure 7.1

All *SIM* and *TABLES* input and output files except DSS files are in standard text format that can be read and viewed with Microsoft WordPad or other editors. The *TABLES* columnar format option facilitates importing the time series into Microsoft Excel or other spreadsheet programs. *TABLES* also converts the time series to records stored in a DSS file to be read by HEC-DSSVue. *SIM* simulation results can be stored directly by *SIM* as DSS or SOU files, but *TABLES* also allows additional data manipulations.

Figure 7.1 and Tables 7.8 and 7.9 were created with the following records to illustrate several of the many options for creating time series plots and tables.

```

2STO  0  4  0  0  0  0  0  0  1
2WSE  1  2  1  2  1
IDEN  Whit
2REG  0  2

```

Figure 7.1 is a plot of monthly regulated flows created with HEC-DSSVue from a DSS file created with *TABLES* as specified by the 2STO record shown above. Defaults are adopted for most of the input parameters as indicated by the zeros in the 2STO record. The parameter TOTALS is activated in 2STO field 9 instructing *TABLES* to work with the totals of all selected reservoirs rather than individual reservoirs. Figure 7.1 is a plot of the summation of the end-of-month storage contents of the six reservoirs in the *Fundamentals Manual* example dataset for each month of the hydrologic period-of-analysis. The summations were performed by *TABLES*. Storage for individual reservoirs could be plotted with HEC-DDSVue from either *SIM* simulation results recorded directly by *SIM* in a DSS file or a DSS file created by *TABLES*.

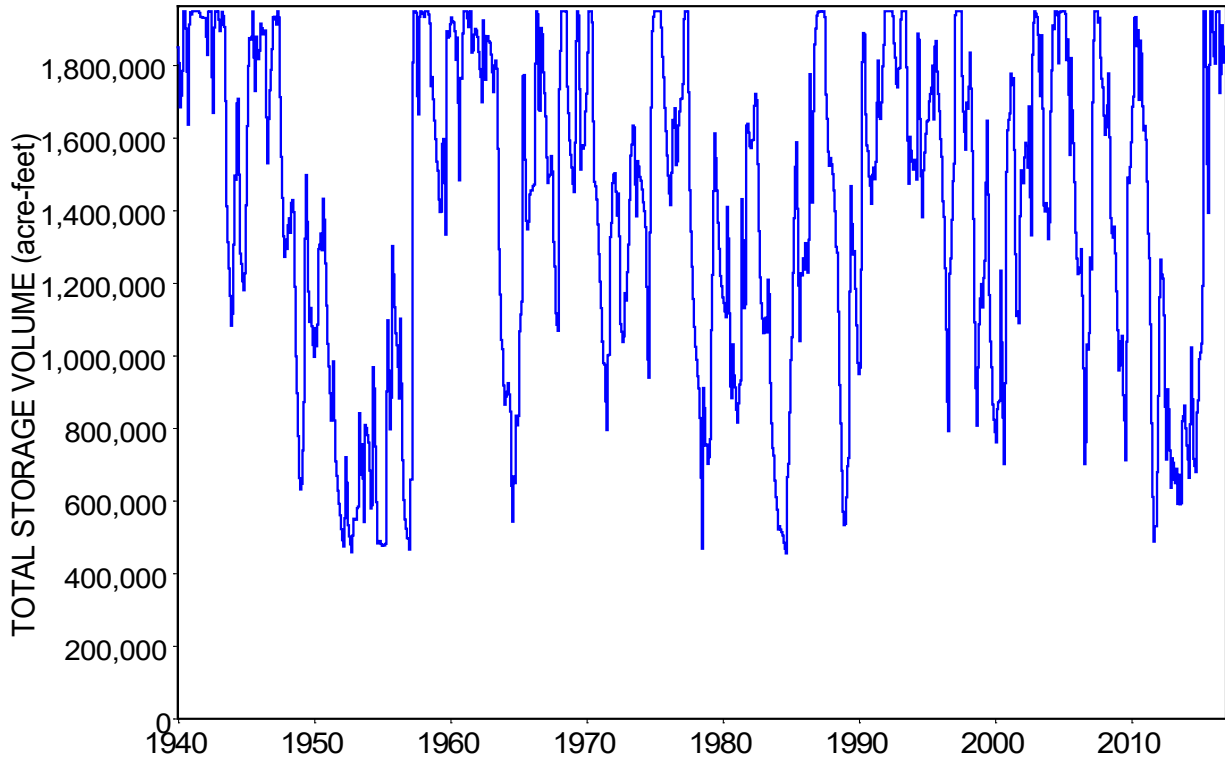


Figure 7.1 Plot of Total Storage in Six Reservoirs Created with HEC-DSSVue

Table 7.8
Example of a Time Series Table with Annual Rows and Monthly Columns

WATER SURFACE ELEVATION FOR RESERVOIR Whit

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1940	533.66	532.89	531.44	531.41	531.08	533.70	533.70	533.70	533.70	532.78	533.70	533.70	532.96
1941	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70
1942	533.61	533.01	532.33	533.70	533.70	533.70	530.98	530.90	532.62	533.70	533.70	533.70	532.97
1943	533.09	532.35	532.90	533.70	533.70	533.70	533.28	529.30	527.92	526.19	525.76	524.23	530.51
1944	523.20	523.95	525.91	525.17	533.70	533.61	530.55	526.37	526.05	524.17	523.16	522.49	526.53
1945	523.82	531.23	533.70	533.70	533.70	533.70	533.70	531.03	529.12	532.26	531.10	530.15	531.44
1946	530.73	533.70	533.70	533.70	533.70	533.70	530.09	529.71	533.44	533.70	533.70	533.70	532.80
1947	533.70	533.70	533.70	533.70	533.70	533.70	533.16	529.69	527.63	526.15	524.95	526.98	530.90
1948	526.81	529.62	530.42	528.98	530.20	531.39	532.17	531.28	529.74	529.37	529.11	528.57	529.80
1949	527.63	528.20	529.76	530.63	533.70	533.70	533.70	533.30	533.05	533.34	532.63	531.56	531.77
1950	531.08	533.70	533.25	533.70	533.70	533.65	533.70	533.70	533.70	533.70	533.54	533.43	533.41
1951	533.33	533.57	533.54	533.48	533.70	533.70	533.18	531.88	530.11	528.57	527.17	525.63	531.49
1952	523.55	521.80	520.98	522.11	525.27	522.10	520.98	520.01	519.23	518.42	520.98	520.98	521.37
1953	520.98	520.98	520.98	520.98	523.14	520.98	520.98	520.53	520.36	520.98	520.98	520.95	521.07
1954	520.96	520.65	520.47	520.95	520.98	522.54	521.60	520.79	520.21	520.80	520.98	520.84	520.98
1955	520.83	520.98	520.98	520.98	528.07	529.47	528.91	528.59	528.32	533.70	533.55	533.41	527.32
1956	533.38	532.89	532.83	533.01	533.70	533.27	532.46	528.55	526.44	525.21	523.58	523.80	529.93
1957	522.14	524.17	523.47	533.70	533.70	533.70	533.70	530.59	531.09	533.70	533.70	533.70	530.61
1958	533.70	533.70	533.70	533.70	533.70	533.53	533.70	533.70	533.70	532.83	531.74	530.89	533.22
1959	529.55	528.94	527.84	527.45	526.51	526.24	528.05	528.51	528.44	533.70	533.70	533.70	529.39
1960	533.70	533.70	533.70	533.70	533.70	533.03	533.70	533.67	532.17	533.70	533.70	533.70	533.52
1961	533.70	533.70	533.70	533.62	533.08	533.70	533.70	533.70	532.46	533.70	533.70	533.70	533.54
1962	533.51	532.77	531.56	531.28	529.78	533.70	533.70	533.70	533.70	533.70	533.70	533.70	532.90
1963	533.43	532.60	532.30	533.70	533.70	533.70	533.28	529.49	529.32	529.33	529.50	528.24	531.55
1964	527.16	526.45	526.51	527.51	527.09	524.34	523.45	520.98	521.92	520.98	525.20	523.78	524.62

1965	523.67	528.90	528.59	528.09	533.70	533.68	530.18	526.53	525.01	523.30	522.15	521.05	527.07
1966	520.98	520.98	520.98	527.68	533.70	533.70	530.40	527.52	533.70	533.70	532.93	532.67	529.08
1967	532.71	531.47	531.44	531.09	530.50	531.89	531.48	530.86	531.52	530.63	529.76	529.30	531.05
1968	533.70	533.70	533.70	533.70	533.70	533.70	533.70	531.46	530.11	528.87	528.06	527.03	531.79
1969	525.51	524.54	528.08	533.70	533.70	533.70	533.65	531.25	530.94	531.95	531.47	531.74	530.85
1970	532.15	533.70	533.70	533.70	533.70	533.35	530.03	529.78	529.44	529.15	527.93	526.71	531.11
1971	525.09	523.49	521.36	520.98	522.56	522.51	520.98	520.81	520.61	531.78	533.08	533.70	524.75
1972	533.70	533.70	533.70	533.70	533.69	533.65	531.00	530.46	531.64	532.64	531.79	530.94	532.55
1973	531.52	532.59	533.37	533.70	533.70	533.70	533.70	533.70	533.05	533.70	533.70	533.69	533.34
1974	533.70	533.56	533.31	532.59	531.63	530.50	530.09	531.82	533.70	533.70	533.70	533.70	532.67
1975	533.70	533.70	533.70	533.70	533.70	533.70	532.50	530.38	528.67	527.06	524.98	523.07	530.74
1976	522.02	520.98	520.98	523.23	528.39	528.42	527.55	523.44	521.27	521.69	523.61	524.05	523.80
1977	523.98	526.50	533.70	533.70	533.70	533.70	532.62	528.69	526.42	525.98	526.24	526.17	529.28
1978	524.61	523.43	521.86	521.69	522.47	520.98	520.30	519.75	519.48	519.70	520.87	521.38	521.38
1979	520.98	520.98	527.20	530.97	533.70	533.70	531.21	528.04	526.42	525.51	523.54	522.98	527.10
1980	521.97	520.98	520.98	520.98	521.73	520.98	520.47	519.74	519.99	519.59	519.98	520.29	520.64
1981	520.20	520.44	521.50	520.98	520.98	528.11	523.95	520.98	520.98	533.70	533.70	533.65	524.93
1982	533.18	533.52	533.70	533.70	533.70	533.70	533.70	533.58	533.23	533.06	533.10	532.07	533.35
1983	530.75	529.86	529.27	528.02	529.55	527.83	523.73	520.98	520.71	520.52	520.44	520.39	525.17
1984	520.98	520.98	520.98	520.55	520.22	519.97	519.31	518.68	518.20	520.98	520.98	522.89	520.40
1985	524.93	523.39	527.34	529.86	531.42	533.70	533.39	532.22	532.42	532.60	531.95	530.98	530.35
1986	529.49	529.78	528.58	527.48	528.57	533.70	530.36	526.58	529.66	533.70	533.70	533.70	530.44
1987	533.70	533.70	533.70	533.70	533.70	533.70	533.52	530.50	528.72	528.28	527.32	526.47	531.42
1988	525.34	524.01	522.41	520.98	520.98	522.24	522.11	520.98	521.04	520.79	520.63	520.98	521.88
1989	520.98	522.35	526.68	527.79	533.70	533.70	532.15	529.22	528.75	528.78	528.63	528.58	528.44
1990	528.44	528.40	532.72	533.70	533.70	533.70	530.53	530.28	530.28	530.56	529.74	528.81	530.91
1991	528.60	528.03	526.53	528.65	529.93	533.70	533.48	533.70	533.15	533.70	533.70	533.70	531.41
1992	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.89	530.66	529.35	528.53	528.88	532.10
1993	528.75	533.26	533.70	533.70	533.70	533.70	530.17	527.35	525.39	529.72	528.90	528.40	530.56
1994	527.81	527.69	527.77	526.84	533.70	533.70	531.36	531.24	532.10	533.70	533.70	533.70	531.11
1995	533.70	533.70	533.70	533.70	533.70	533.70	532.77	533.70	533.70	532.83	532.33	531.58	533.26
1996	530.57	530.82	529.54	529.54	529.25	527.90	527.47	527.33	531.87	532.73	533.70	533.70	530.37
1997	533.70	533.70	533.70	533.70	533.70	533.70	533.70	531.02	529.89	528.68	527.49	528.46	531.79
1998	527.73	528.84	532.14	530.50	529.01	528.45	523.81	523.65	521.39	523.04	523.45	522.63	526.22
1999	524.06	521.95	524.13	526.60	529.76	533.70	533.30	529.50	529.50	529.42	529.35	528.33	528.30
2000	527.15	526.05	528.05	528.37	527.76	533.70	533.28	532.64	530.43	533.70	533.70	533.70	530.71
2001	533.70	533.70	533.70	533.27	533.70	532.24	528.41	524.16	524.22	523.21	526.90	526.76	529.50
2002	526.59	525.79	527.85	529.63	530.17	532.06	533.70	530.94	529.22	533.70	533.70	533.70	530.59
2003	533.70	533.70	532.89	531.65	530.91	533.70	533.35	530.02	528.95	528.57	528.30	527.14	531.08
2004	527.84	532.74	533.59	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.12
2005	533.70	533.70	533.70	532.93	533.70	533.70	533.70	533.70	533.58	533.70	533.48	532.29	533.49
2006	532.20	531.03	531.74	531.47	533.70	532.67	532.51	528.62	531.78	532.83	532.22	531.96	531.89
2007	533.70	532.88	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.05	531.85	531.49	533.24
2008	530.23	529.54	530.02	531.15	533.70	533.18	532.61	533.70	533.49	533.70	533.56	533.56	532.37
2009	533.46	532.64	531.83	533.27	533.70	533.39	533.70	530.71	533.70	533.70	533.50	533.70	533.11
2010	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.32	533.70	533.70	532.81	531.67	533.43
2011	530.70	529.51	527.98	526.06	526.02	525.38	520.98	520.27	519.76	522.39	521.33	521.68	524.34
2012	523.52	525.27	527.30	527.49	527.59	528.05	523.74	520.98	528.82	527.32	525.11	523.32	525.71
2013	522.97	521.88	520.98	520.80	520.98	522.66	527.49	523.34	522.22	522.24	521.37	521.62	522.38
2014	520.98	520.98	520.98	520.98	524.27	528.08	528.56	528.85	528.42	527.62	530.51	529.60	525.82
2015	530.42	530.64	530.65	533.70	533.70	533.70	533.70	530.30	530.02	533.70	533.70	533.70	532.33
2016	533.09	532.28	531.41	533.70	533.70	533.70	533.34	533.70	533.70	533.70	533.70	532.90	533.24
MEAN	528.77	528.97	529.38	529.88	530.82	531.22	530.30	528.80	528.72	529.40	529.25	528.94	529.54

Table 7.9
Example of an Annual Time Series Table in Columnar Format

	2WSE Whit	2REG EK	2REG Whit	2REG WacoL	2REG WacoG	2REG High	2REG Belton	2REG George	2REG Grang	2REG Camer	2REG Bryan	2REG Herp
1940	533.	609001.	960729.	275650.	1595488.	2091745.	388950.	90033.	317961.	1667116.	4069374.	5230438.
1941	534.	3258658.	4088860.	701302.	5246122.	6023742.	1326346.	119437.	400416.	2893716.	9373738.	10168254.
1942	533.	1091769.	2161094.	700655.	3507055.	3984543.	1027976.	17590.	93679.	1757191.	5969282.	6136876.
1943	531.	191472.	227080.	26167.	538375.	656775.	169436.	581.	60528.	335620.	1215691.	599202.
1944	527.	0.	95729.	372480.	1185721.	1952194.	798961.	80998.	222854.	2089561.	4958004.	6326106.
1945	531.	61243.	772640.	712472.	2261323.	2939840.	738048.	41469.	191328.	1834488.	5520312.	7158669.
1946	533.	348926.	805975.	259621.	1394813.	1937701.	478641.	36337.	159948.	1372540.	4159946.	5896788.

1947	531.	553023.	758965.	129949.	1185364.	1436983.	214201.	34459.	127755.	773459.	2482867.	3058912.
1948	530.	423235.	397417.	0.	661638.	708589.	170817.	7299.	50879.	221417.	1013219.	397094.
1949	532.	287670.	617234.	53665.	966205.	1108343.	39896.	1055.	1601.	302202.	1480655.	1972914.
1950	533.	314369.	565292.	2554.	733922.	828173.	30539.	0.	0.	111455.	1183616.	1699287.
1951	531.	479709.	581872.	0.	729455.	741526.	6238.	223.	978.	19331.	751985.	126380.
1952	521.	0.	11527.	0.	295623.	357764.	36558.	5357.	27418.	125928.	528657.	423104.
1953	521.	311565.	291275.	116586.	657966.	925640.	67617.	9972.	57283.	534172.	1922486.	2332379.
1954	521.	578285.	565532.	4449.	649426.	659862.	0.	240.	12957.	34008.	705986.	152468.
1955	527.	745162.	656107.	0.	723229.	813685.	43470.	146.	12751.	203856.	1125560.	514121.
1956	530.	343309.	421923.	0.	669148.	697077.	65439.	739.	4630.	63290.	740742.	172571.
1957	531.	2714494.	4214253.	610614.	5466660.	6325138.	750795.	71338.	268549.	2465544.	9549538.	10705770.
1958	533.	518701.	1075369.	283024.	1657934.	2066386.	425210.	53830.	193716.	1368984.	3797275.	3858604.
1959	529.	273990.	636100.	324988.	1277302.	1622186.	312846.	52656.	201883.	1006910.	2861821.	3123041.
1960	534.	310469.	593190.	239039.	1086534.	1586832.	382409.	50158.	188783.	1461196.	3638644.	4300030.
1961	534.	590596.	1132168.	815859.	2376676.	2965763.	744179.	55407.	201404.	1963514.	5327166.	6533172.
1962	533.	695802.	1004347.	32759.	1364654.	1449847.	11491.	0.	19489.	270058.	1737520.	1135906.
1963	532.	613560.	626305.	0.	767594.	788986.	189043.	216.	2494.	235751.	1011721.	386245.
1964	525.	122776.	132330.	45018.	562659.	649382.	200982.	163.	19456.	356397.	872082.	326885.
1965	527.	0.	204909.	537758.	1420839.	2138718.	632922.	67994.	225711.	2238349.	4871668.	5390774.
1966	529.	670024.	781232.	284373.	1680901.	2197728.	282120.	6458.	182543.	1047579.	3537330.	3567058.
1967	531.	461193.	465454.	0.	718489.	901991.	147851.	349.	33112.	330808.	1287251.	377032.
1968	532.	289857.	1231098.	760660.	2612589.	3182170.	645474.	75158.	277405.	1978288.	5728751.	7760749.
1969	531.	668249.	1069827.	240160.	1817222.	1984233.	80793.	40771.	207869.	735114.	3080392.	3673540.
1970	531.	237710.	635466.	279405.	1285788.	1517781.	419996.	81080.	170862.	1172934.	2991582.	3014302.
1971	525.	325043.	489990.	180616.	995128.	1170534.	200295.	0.	21092.	317112.	1562599.	816879.
1972	533.	427068.	531342.	62433.	732332.	829454.	124787.	837.	21473.	298398.	1274113.	684514.
1973	533.	83038.	735008.	270864.	1620335.	2455747.	0.	10191.	161342.	750841.	3750302.	5640343.
1974	533.	286341.	647077.	176906.	1214615.	1855356.	10059.	111456.	239621.	849777.	3111344.	4222392.
1975	531.	317624.	859090.	273325.	1625002.	2169473.	395083.	93628.	262446.	1598686.	4083615.	4698440.
1976	524.	38536.	10265.	168210.	884298.	1496908.	30504.	62887.	140206.	817571.	3001271.	3625283.
1977	529.	296852.	735428.	474269.	1796692.	2186729.	635084.	34925.	200224.	1450916.	4107441.	4502425.
1978	521.	609910.	469119.	0.	626988.	655898.	136064.	2818.	2842.	151551.	866061.	344537.
1979	527.	0.	375544.	216761.	1102628.	1771885.	0.	24114.	150792.	1085032.	4006039.	5413426.
1980	521.	426526.	388244.	40756.	732095.	950768.	127513.	27013.	104617.	465716.	1691516.	1578925.
1981	525.	685865.	855912.	81670.	1341240.	1701424.	0.	87522.	248457.	847716.	2853210.	2973101.
1982	533.	1620380.	2178619.	146732.	2378280.	2552553.	0.	21010.	116951.	291823.	2886290.	2505009.
1983	525.	171506.	144566.	56351.	571000.	706517.	17860.	52381.	126044.	415162.	1367343.	2031184.
1984	520.	64577.	73308.	37377.	298943.	484215.	7356.	2382.	2265.	165607.	792868.	1607094.
1985	530.	370905.	320969.	159387.	881947.	1232572.	1215.	21441.	157528.	642731.	2303632.	2959400.
1986	530.	449206.	483840.	303403.	1370110.	1906428.	217249.	49132.	192575.	1132109.	3587265.	4059530.
1987	531.	691822.	1371457.	174724.	1859538.	2265494.	526888.	74275.	322455.	1747860.	4545412.	5061100.
1988	522.	371580.	346961.	24064.	620917.	653455.	307272.	9034.	19808.	344042.	1065538.	320118.
1989	528.	217072.	1071328.	326572.	1887671.	2272694.	21940.	0.	9927.	123254.	2614875.	2234006.
1990	531.	1205642.	2442087.	337548.	3208565.	3517465.	425623.	0.	0.	596173.	4468692.	4140677.
1991	531.	1167619.	2328825.	713538.	3728923.	4296281.	499456.	20250.	179797.	1748652.	6860380.	8040622.
1992	532.	1557606.	2764203.	774145.	4194307.	5264051.	1466568.	197116.	545257.	3974801.	10865708.	13081757.
1993	531.	119949.	328099.	219820.	1000360.	1460896.	446216.	67227.	227597.	1259514.	3401204.	4551339.
1994	531.	325011.	544409.	308315.	1307384.	1406230.	259671.	0.	0.	492197.	2141967.	3183713.
1995	533.	15961.	1034979.	752433.	2385516.	2553002.	495266.	0.	48983.	934183.	3911190.	3813152.
1996	530.	243636.	404225.	74481.	829898.	969121.	317426.	439.	16099.	444884.	1578752.	589415.
1997	532.	367363.	1756457.	965649.	3537544.	4254010.	1148267.	98069.	456690.	2974912.	8049298.	7975068.
1998	526.	205360.	203779.	371242.	850051.	972190.	406006.	66646.	270503.	1765028.	2500225.	4126664.
1999	528.	252934.	276464.	40960.	646982.	740045.	135998.	36728.	77157.	320473.	1040904.	875661.
2000	531.	231832.	464683.	397928.	920648.	1134601.	65231.	28299.	114895.	1137448.	2583922.	3855416.
2001	529.	0.	266573.	329421.	952196.	1256669.	470130.	60813.	208843.	1297132.	2736281.	3049538.
2002	531.	131247.	408611.	229684.	1382846.	1555008.	138200.	80345.	185615.	910771.	2412983.	2893514.
2003	531.	280070.	698421.	193856.	1246679.	1135949.	227580.	13888.	77753.	614335.	1783619.	1687854.
2004	533.	1301454.	2253963.	933679.	2945800.	3744094.	820337.	122784.	437482.	2943392.	7920357.	9144320.
2005	533.	657703.	1070250.	106625.	1377684.	1209229.	196539.	15383.	62352.	490517.	1519001.	1545476.
2006	532.	221754.	223282.	0.	571750.	662210.	142162.	0.	39373.	342705.	1142946.	1159789.
2007	533.	914043.	2309943.	1383674.	3665392.	4656152.	1378236.	148471.	516064.	3752514.	9888152.	10209817.
2008	532.	388080.	624675.	68911.	813590.	1006586.	146474.	0.	29937.	248740.	1479610.	1125956.
2009	533.	206855.	743169.	676739.	1376607.	1837340.	373832.	58713.	235419.	1522484.	3861993.	4652826.
2010	533.	682377.	1458425.	352041.	1386296.	1675188.	313608.	31075.	111065.	839158.	2662552.	3047001.
2011	524.	249037.	242888.	24678.	588209.	581156.	285736.	6316.	50897.	564897.	941320.	567439.
2012	526.	0.	0.	386256.	948045.	1119626.	403371.	21407.	169185.	1152701.	2175216.	2275229.
2013	522.	30845.	51154.	284120.	577263.	724719.	102562.	11251.	126333.	1072289.	1543742.	2099223.
2014	526.	257136.	284140.	131848.	460928.	570483.	111494.	38824.	127218.	653678.	1375487.	1424393.
2015	532.	1191439.	2958298.	1413967.	4592802.	5839286.	1458816.	123438.	637971.	3844708.	11562115.	12572489.
2016	533.	638502.	1516579.	605591.	2698406.	3281430.	543170.	31057.	268742.	1402698.	4847148.	5386268.

Reliability and Frequency Analyses

The WRAP simulation models *SIM*, *SIMD*, and *SALT* simulate

- development, management, allocation, regulation, and use of the water resources of a river basin or region in accordance with water use requirements and institutional water allocation systems utilizing constructed facilities including reservoir projects, conveyance systems, and hydroelectric power plants
- during each sequential period (month or day) of a hydrologic period-of-analysis with river basin hydrology represented by sequences of monthly naturalized stream flows and net evaporation-precipitation depths.

Capabilities are assessed for meeting water use requirements under a defined scenario of water resources development and management during given sequences of naturalized flows and net reservoir evaporation-precipitation rates. The future is of concern, not the past. However, since future hydrology is unknown, historical past stream flows and reservoir evaporation-precipitation rates are typically adopted as being statistically representative of the hydrologic characteristics of a river basin that can be expected to continue into the future. The results of a WRAP simulation are viewed from the perspectives of frequency, probability, percent-of-time, or reliability of meeting water supply, instream flow, hydropower, and/or reservoir storage requirements.

Concise measures of water availability and reliability are necessary in analyzing and displaying simulation results and assessing water management capabilities. *TABLES* options include the following likelihood (frequency or probability) based metrics for concisely summarizing *SIM*, *SIMD*, and *SALT* simulation results. The reliability and frequency tables may be developed either considering all months or alternatively for a specified individual month of the year such as July or November.

- volume and period reliability tables for water supply diversion and hydroelectric energy generation targets (2REL, 6REL, 8REL records)
- frequency tables for naturalized, regulated, and unappropriated flows, reservoir storage volumes and water surface elevations, and instream flow shortages (2FRE, 2FRQ, 6FRE, 6FRQ, 8FRE, 8FRQ records)
- reservoir drawdown-duration and storage-reliability tables (2RES, 6RES records)

The basic reliability and frequency analysis methods implemented in *TABLES* were originally developed for application to the results of a monthly *SIM* simulation but are also applicable to the daily results of a *SIMD* simulation. Flood frequency as well as water supply reliability are relevant in daily *SIMD* applications. The basic methods are applicable to short-term CRM as well as conventional long-term simulations. *SALT* adds salinity considerations.

Metrics for estimating and communicating likelihood are covered in the *Reference*, *Users*, *Fundamentals*, *Salinity*, and *Daily Manuals*. This present *Reference Manual* Chapter 7 generally provides more complete detailed explanations of the statistical concepts and methods. Table 7.10 lists the various parts of the WRAP manuals that cover reliability and frequency analysis capabilities.

Table 7.10
Outline of Sections of Manuals Dealing with Frequency and Reliability Analyses

Reference Manual

- Chapter 2 Overview
 - Volume and Period Reliability, Shortage Metrics, Frequency Analyses
- Chapter 5 Organization and Analysis of Simulation Results
- Chapter 6 Analyzing Simulation Results
 - Yield versus Reliability Relationships Including Firm and Safe Yields
- Chapter 7 Program *TABLES* Analyses of Simulation Input and Results
 - DATA Record Transformation of Simulation Results Data
 - Water Supply and Hydropower Reliability Analyses
 - Frequency Analyses
 - Reservoir Contents, Drawdown Duration, and Storage Reliability
- Chapter 8 Short-Term Conditional Reliability Modeling
 - Reliability, Frequency, Regression, and Correlation Analyses

Users Manual

- Chapter 5 Program *TABLES*
 - DSSM, DSSD, 7DSS Analyses of any monthly, daily, or annual data from DSS file
 - DATA Record – Data Transformation for Time Series and Frequency Tables
 - 2REL Record – Diversion or Hydropower Reliability Summary
 - 2FRE Record – Flow-Frequency or Storage-Frequency Relationships
 - 2FRQ Record – Frequency for Specified Flow or Storage
 - 2RES Record – Reservoir Content, Draw-Down Duration, and Storage Reliability
 - 5CRM, 5CR1, 5CR2 Records – Conditional Reliability Modeling
 - 6REL Record – Water Supply Diversion or Hydropower Reliability
 - 6FRE Record – Flow or Storage Frequency Relationships
 - 6FRQ Record – Frequency for Specified Flow or Storage
 - 6RES Record – Reservoir Storage and Drawdown Frequency
 - 7FFA Record – Flood Frequency Analysis

Fundamentals Manual

Presentation of an example that is further employed in the other manuals.

Daily Manual

- Chapter 9 Frequency Analyses of Annual Series from a Daily Simulation
- Appendix A Program *Daily Flows*
 - FREQ Record – Frequency Analysis
 - REGCOR Record – Regression and Correlation Analyses

Salinity Manual

- Explanation of *TABLES* 8FRE, 8FRQ, and 8REL input records.
- 8FRE Record – Frequency Analysis of Salinity Loads and Concentrations
- 8FRQ Record – Frequency Analysis of Salinity Loads and Concentrations
- 8REL Record – Water Supply Reliability Constrained by Salinity

Short-term conditional reliability modeling (CRM) is described in Chapter 8. *TABLES* 2REL, 2FRE, 2FRQ, and 2RES records are applied in short-term CRM as well as conventional long-term reliability and frequency analyses. The resulting 2REL, 2FRE, 2FRQ, and 2RES record tables include CRM parameters in the headings but otherwise have the same appearance as long-term analysis. The quantities in the tables are interpreted differently as explained in Chapter 8. A *SIMD* CRM simulation can be performed with a daily computational time step, but the results are aggregated to monthly for reliability and frequency analyses. Thus, 6REL, 6FRE, 6FRQ, and 6RES records are not applicable for CRM.

TABLES types 2 and 6 records deal with monthly and daily, respectively, simulation results. 2RES and 6RES records build three tables summarizing reservoir storage contents that include storage and draw-down frequency relationships. 2REL and 6REL records build diversion and hydropower reliability tables. 2FRE, 2FRQ, 6FRE, and 6FRQ records, combined with the *DATA* record, build frequency tables for any simulation results variables or revisions thereof. *DSSM* and *DSSD* records allow frequency analyses of any data series from any *DSS* file.

The utility programs *HYD* and *DAY* designed for compiling monthly and daily hydrology input datasets for the *SIM* and *SIMD* simulation models also include statistical analysis routines based on the basic concepts and methods addressed in this chapter.

Salinity simulation capabilities are documented by the *Salinity Manual*. Frequency analyses of salt loads and concentrations of stream flow and reservoir storage are performed with 8FRE and 8FRQ records, which are analogous to 2FRE and 2FRQ records. The frequency analysis computations are the same regardless of the variable from the *SIM* or *SALT* simulation results dataset that is being analyzed. The 8REL record is analogous to the 2REL record.

Water Supply and Hydropower Reliability

Reliability tables for meeting water supply diversion and hydroelectric energy generation requirements are developed with the 2REL, 6REL, and 8REL records. The monthly 2REL and daily 6REL reliability tables reflect the same basic concepts and components. The 8REL record routine adds consideration of maximum allowable salinity concentrations. This chapter focuses on 2REL reliability analysis of monthly *SIM* simulation results.

The 2REL record applies only to *WR* record water rights, not *IF* record rights. The 2FRE record includes a somewhat analogous option for expressing instream flow shortages as a percent of instream flow targets.

A 2REL reliability table contains both volume and period reliabilities. An optional auxiliary table of shortage metrics activated by 2REL record field 7 provides additional supplemental measures of water supply capabilities.

Volume and Period Reliabilities

Volume reliability is the percentage of the total target demand amount that is actually supplied. For water supply diversions, the amounts are volumes. For hydroelectric power, the

amounts are kilowatt-hours of energy generated. Volume reliability (R_V) is the ratio of volume of water supplied or the energy produced (v) to the target (V), converted to a percentage.

$$R_V = \frac{v}{V} (100\%) \quad (7.1)$$

Equivalently, for water supply, R_V is the mean actual diversion rate as a percentage of the mean target diversion rate. For hydropower, R_V is the mean actual rate of energy production as a percentage of the mean target energy production rate.

Period reliability is the percentage of the total number of periods of the simulation during which the specified demand target is either fully supplied or at least a specified percentage of the target is supplied. The various variations of period reliability (R_P) are computed by *TABLES* from the results of a *SIM* simulation as:

$$R_P = \frac{n}{N} (100\%) \quad (7.2)$$

where n denotes the number of periods during the simulation for which the specified percentage of the demand target is met, and N is the total number of periods considered. The 2REL record develops a reliability table with periods defined alternatively in terms of both months and years. The 2REL record allows N and n to be defined on a monthly basis optionally either considering all months or only months with non-zero demand targets. The 6REL record described in the *Daily Manual* allows use of *SIMD* results with a sub-monthly time step such as a day.

Whereas volume reliabilities are based on total diversion volumes or hydroelectric energy amounts, period reliabilities are based on percent-of-time. Period reliability R_P is an expression of the percentage of time that the full demand target or a specified portion of the demand target can be supplied. Equivalently, R_P represents the likelihood or probability of the target being met in any randomly selected month or year. The volume reliability R_V provides a greater focus on the relative magnitude of the shortage amounts.

TABLES 2REL Tables

The following versions of reliability tables may be created by specifying ID options in 2REL record field 4.

- Default (ID=0): reliabilities for selected control points
- ID option 1: reliabilities for selected individual water rights
- ID option 2: reliabilities for selected hydroelectric power reservoirs
- ID option 3: reliabilities for selected water right groups

With ID option 1, the reliability metrics are for individual water rights. The first column is a list of water rights. With the default ID option 0 (blank field), diversion targets and shortages for all water rights located at each control point are summed and reliability metrics are computed for the control point totals. The first column of the table is a list of control points. Likewise, reservoir hydropower reliability table (ID=2) reflects the summation of all hydropower targets and shortage at the reservoir. Likewise, reliability metrics for ID option 3 are for the aggregation of all rights in each group.

A 2REL reliability table may include all control points, water rights, or reservoirs included in the *SIM* output OUT file, which is controlled by *SIM* input parameters. Alternatively, selected control points, water rights, reservoirs, or water right groups may be listed on IDEN records. The DSSM record allows the 2REL record to use with a *SIM* output DSS file.

The input parameter FAMT can be used to reduce the length of a 2REL table. Only those control points (ID=0), water rights (ID=1), reservoirs (ID=2), or water right groups (ID=3) with mean annual targets greater than FAMT are included in the table. FAMT has a default of 0.0.

Another alternative option based on criteria defining a sub-set of rights can be used with 2REL tables for individual water rights (ID=1) to control the selection of water rights included in the table. Parameters XAMT, XPS, XPS, XCP, XGROUP, and XUSE in fields 7-12 of the 2REL record are designed to reduce the length of a 2REL table by defining a subset of water rights to include in the table. These 2REL table criteria are similar to the criteria employed by the 1SRT and 1SUM records discussed earlier in this chapter. Any or all of the criteria may be activated. A water right must satisfy all activated criteria in order to be included in the table. The criteria defined by each parameter are as follows.

- XAMT Lower limit on annual diversion from *WR* record field 3.
- XPS Priority number must be less than (senior to) XPS.
- XPJ Priority number must be greater than (junior to) XPJ.
- XPJ Water right must be located at one of the control points listed on IDEN records.
- XGROUP Water right must be included in one of the groups listed on IDEN records.
- XUSE USE from *WR* record field 3 must be XUSE.

The lower limits FAMT and XAMT differ as follows. FAMT applies to control point and reservoir aggregations of water rights as well as individual water rights. XAMT refers only to individual water rights. XAMT refers to the annual amount in *WR* record field 3. FAMT is an annual mean of computed targets that may reflect target adjustments.

The tables presented here to illustrate the format of tables produced with *TABLES* are from the example presented in the *Fundamentals Manual*. Tables 7.11 and 7.12 illustrate the format of water supply diversion and hydropower reliability tables created with the two 2REL records copied below which reflect defaults for most of the input parameters.

```

2REL  0  0  1
2REL  0  0  2  1
IDEN  Whit

```

Table 7.11 is a reliability table for all individual water rights (ID option 1). No options are activated for reducing the number of water rights included in the table. Table 7.12 illustrates the format of reliability tables for reservoir/hydropower projects (ID option 2).

As indicated in Table 5.1, hydroelectric energy targets and shortages are stored on both reservoir/hydropower output records and water right records. Multiple water rights with different priorities may generate energy at the same reservoir. However, only the cumulative total energy associated with the most junior right, which is computed last in the priority sequence, is written to the OUT file on reservoir/hydropower records and included in a 2REL record reliability table for

reservoir/hydropower projects. The intermediate cumulative energy amounts generated by the senior rights are recorded on water right output records and may be included in a water right reliability table.

Table 7.11
Reliability Table for the Example in the *Fundamentals Manual*

RELIABILITY SUMMARY FOR SELECTED WATER RIGHTS

NAME	TARGET	MEAN	*RELIABILITY*		PERCENTAGE OF MONTHS							PERCENTAGE OF YEARS							
	DIVERSION (AC-FT/YR)	SHORTAGE (AC-FT/YR)	PERIOD	VOLUME	WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET		100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%
WR-6	60000.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
WR-1	9800.0	96.69	98.70	99.01	98.7	98.7	98.8	98.9	99.1	99.1	99.2	90.9	92.2	92.2	94.8	100.0	100.0	100.0	100.0
WR-2	245000.0	9870.66	94.16	95.97	94.2	94.3	94.5	94.8	95.7	96.5	98.6	80.5	81.8	83.1	87.0	94.8	97.4	97.4	97.4
WR-14	11300.0	158.46	98.92	98.60	98.9	98.9	98.9	99.0	99.0	99.1	99.4	90.9	90.9	92.2	96.1	98.7	98.7	98.7	98.7
WR-20	34500.0	314.37	99.13	99.09	99.1	99.1	99.2	99.2	99.4	99.6	99.6	89.6	89.6	92.2	97.4	100.0	100.0	100.0	100.0
WR-22	49600.0	1294.40	97.94	97.39	97.9	98.2	98.4	98.6	99.0	99.0	99.2	80.5	83.1	87.0	92.2	96.1	100.0	100.0	100.0
WR-16	32300.0	2380.99	95.56	92.63	95.6	95.9	96.1	96.3	96.8	96.9	97.2	62.3	68.8	70.1	77.9	81.8	97.4	97.4	97.4
WR-17	44800.0	4671.20	94.70	89.57	94.7	94.8	95.0	95.5	96.0	96.5	96.8	55.8	58.4	59.7	67.5	75.3	94.8	94.8	94.8
WR-13	18200.0	831.32	96.00	95.43	96.0	96.0	96.0	96.3	96.6	96.9	96.9	72.7	72.7	74.0	76.6	93.5	100.0	100.0	100.0
WR-19	39000.0	2050.68	95.78	94.74	95.8	95.8	95.8	95.9	96.2	96.4	96.6	67.5	67.5	67.5	72.7	92.2	100.0	100.0	100.0
WR-21	95600.0	6245.38	94.59	93.47	94.6	94.8	94.9	95.0	95.2	95.3	96.0	61.0	62.3	62.3	64.9	90.9	100.0	100.0	100.0
WR-8	82760.0	4120.81	93.94	95.02	93.9	93.9	94.4	94.6	94.8	95.5	97.0	83.1	83.1	85.7	87.0	92.2	97.4	97.4	97.4
WR-9	97500.0	6508.18	92.32	93.32	92.3	92.5	92.5	92.7	93.3	93.4	93.8	79.2	80.5	81.8	84.4	90.9	93.5	93.5	93.5
WR-10	25610.0	4251.55	79.00	83.40	79.0	79.4	79.5	81.2	83.1	85.4	94.3	53.2	54.5	57.1	63.6	74.0	84.4	84.4	84.4
WR-11	42000.0	3561.08	87.88	91.52	87.9	88.1	88.5	89.3	91.6	94.0	97.2	63.6	64.9	68.8	77.9	89.6	93.5	93.5	93.5
WR-3	18000.0	998.79	94.48	94.45	94.5	94.5	94.6	94.6	94.6	94.9	95.1	83.1	83.1	83.1	84.4	89.6	96.1	96.1	96.1
WR-12	92100.0	31627.97	80.52	65.66	80.5	81.2	81.6	82.7	85.7	89.8	93.5	14.3	15.6	19.5	20.8	35.1	72.7	72.7	72.7
WR-18	25400.0	3309.79	89.07	86.97	89.1	89.1	89.1	89.2	89.5	89.8	90.2	37.7	37.7	40.3	41.6	81.8	98.7	98.7	98.7
WR-7	20800.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
WR-15	88000.0	4209.25	94.91	95.22	94.9	94.9	95.1	95.2	95.5	95.9	96.3	87.0	87.0	87.0	88.3	92.2	93.5	93.5	93.5
WR-23	74500.0	23506.57	85.39	68.45	85.4	85.4	85.4	85.8	87.0	87.9	89.0	26.0	28.6	28.6	35.1	42.9	63.6	63.6	63.6
WR-24	900000.1	29923.05	95.56	96.68	95.6	95.7	95.8	95.9	96.5	97.8	98.9	81.8	83.1	84.4	90.9	94.8	98.7	98.7	98.7
Total	2106770.0	139931.17			93.36														

Table 7.12
Hydropower Reliability Table for the Example in the *Fundamentals Manual*

RELIABILITY SUMMARY FOR SELECTED HYDROELECTRIC POWER PROJECTS

NAME	ENERGY	MEAN	*RELIABILITY*		PERCENTAGE OF MONTHS							PERCENTAGE OF YEARS									
	TARGET	SHORTAGE	PERIOD	AMOUNT	WITH ENERGY GENERATION EQUALING OR EXCEEDING PERCENTAGE OF TARGET		100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%	
Whit	36000.0	1853.81	91.88	94.85	91.9	92.1	92.2	92.7	95.1	96.1	99.4	74.0	74.0	76.6	83.1	93.5	97.4	100.0	100.0	100.0	
Total	36000.0	1853.81			94.85																

The reliabilities may be for a specified single month of the year such as August or for all 12 months. The reliabilities in Tables 7.11 and 7.12 are for all months as indicated by no month being identified in the table headings. The reliabilities represent probabilities of supplying demands irrespective of season of the year. If August tends to be dry, reliabilities of meeting demands in August computed based on frequency counts considering only August will be lower.

A reliability summary includes tabulations of period reliabilities expressed both as the percentage of months and the percentage of years during the simulation during which diversions

or energy produced equaled or exceeded specified magnitudes expressed as a percentage of the target demand. For example, the table shows the percentage of months in the simulation for which the computed diversion equals or exceeds 75% of the monthly diversion target. It also shows the percentage of years for which the total diversions during the year equal or exceed 75% of the annual target amount. The table also shows the percentage of months for which the demand is fully 100% supplied, without any shortage.

Water right WR-1 in Table 7.11 has a mean annual diversion target of 9,800 acre-feet/year, mean annual shortage of 96.69 acre-feet/year, and a corresponding (Equation 7.1) volume reliability of 99.01 percent. Period reliabilities are based on Equation 7.2. The monthly diversion targets are fully met during 98.70 percent of the 924 months of the 1940-2016 hydrologic period of analysis. At least 90 percent of the monthly target is supplied during 98.8% of the 924 months. At least 90 percent of the annual target is supplied during 92.2% of the 77 years of the simulation.

Reliabilities for hydroelectric power generation at Whitney Reservoir (reservoir identifier Whit) are shown in Table 7.12. The monthly hydropower targets sum to a total annual target of 36,000 kilowatt-hours/year. The mean annual shortage is 1,853.8 kilowatt-hours/year, and thus the mean annual energy production from Equation 7.1 is 94.85 percent of the target. The energy target is fully met during 91.88 percent of the 724 months (Equation 7.2). Energy production equals or exceeds 75 percent of the target during 92.7 percent of 724 months and during 93.5 percent of the 77 years of the 1940-2016 hydrologic period of analysis simulation.

These reliability metrics may be interpreted as follows. The WR-1 diversion shown in Table 7.11 equals or exceeds 90 percent of the monthly target an estimated 98.8 percent of the time. At least 90 percent of the annual demand is supplied an estimated 94.8 percent of the time. The estimated probability of supplying at least 90 percent of the monthly target in any randomly selected future month is 0.988. The estimated probability of supplying at least 90 percent of the annual target in any randomly selected future year is 0.948.

These estimates reflect all of the premises and approximations inherent in the modeling system and thus are necessarily approximate. Hydrologic variables such as river flows are highly variable, stochastic, and uncertain. The model and resulting reliabilities are typically based on the premise that historical natural hydrology is statistically representative of the climatic and hydrologic characteristics of the river basin to be expected in the future. Data describing the physical and institutional features of water management are also necessarily approximate. Uncertainties are inherent in modeling water management and use practices as well as river basin hydrology.

An optional supplemental table is activated by 2REL record input parameter TAR that allows a target to be input for use in computing volume reliability for the aggregate of all of the rights in the 2REL table. *SIM* has a variety of options for specifying diversion and hydroelectric energy targets as a function of reservoir storage and stream flow. An option activated by the *SO* record allows specification of which original, intermediate, or final target developed during the target building process is written to the *SIM* output file. The default is to write the last target and shortage amount to the output file. *TABLES* reads the values written in the *SIM* output file and computes the water supply diversion or energy generated as the target less the shortage. The TAR option on the *2REL* record allows user-specification of the target to be adopted by *TABLES* for the volume reliability quantities recorded in the supplemental TAR option table.

Additional Metrics of Water Supply and Hydropower Capabilities

The 2REL record reliability analysis features described in the preceding section provide basic conventional volume reliability and period reliability metrics for assessing water supply and hydroelectric energy generation capabilities. WRAP also provides the two following additional sets of metrics for summarizing the results of *SIM* simulations.

1. Firm and safe yield metrics are developed as specified by the *FY* record in the *SIM* input DAT file as described in the preceding Chapter 6. *TABLES* is not involved.
2. An additional table created by the parameter *VUL* in 2REL record field 14 includes the maximum shortage, vulnerability, resiliency, average severity, shortage index, average number of failures per sequence, and maximum number of consecutive shortages.

An additional table summarizing failures to supply diversion requirements is created with the 2REL record *VUL* switch along with the standard reliability table. The *VUL* option is applicable to the results of conventional long-term simulations covered in this chapter or short-term conditional reliability modeling (CRM) covered in Chapter 8. In CRM, the sequence length is an integer number of months defined by the parameter *CR1* on the *CR* record. For a conventional long-term simulation, the metrics are computed either by treating the conventional simulation as a single sequence with the length being the entire period-of-analysis or by treating each year (12 months from January through December) as a sequence. The supply failure metrics are defined as follows.

A shortage volume in a particular month of the simulation is the diversion target less the actual diversion as constrained by water availability. Shortages represent failures to fully meet water supply diversion requirements. A shortage period is defined as one or more consecutive months of a simulation during which a failure to meet the full diversion target occurs in each of the months.

The metrics are defined as follows in the order in which they are tabulated on the 2REL record *VUL* option shortage summary table. Although any set of consistent units may be adopted in a *SIM* simulation, acre-feet is used below to represent any volume unit.

Maximum Shortage – The maximum shortage in any month during the entire simulation.

Vulnerability – The average maximum shortage that occurred during each sequence in which a shortage occurred. In the case of a conventional long-term simulation, sequence length is defined on a January–December yearly basis.

Resiliency – The inverse of the mean of the average length of the shortage periods that occurred during each sequence, counting only those sequences for which shortages occurred.

Average Severity – the average sum of consecutive shortages that occurred during each sequence counting only those sequences during which shortages occurred.

Shortage Index:
$$\text{Shortage Index} = \frac{100}{\text{months}} \sum \left(\left(\frac{\text{annual or sequence shortage}}{\text{annual or sequence target}} \right)^2 \right)$$

Average Number of Failures per Sequence – average number of months of consecutive shortage that occurred during each sequence including those sequences during which no shortage occurred. In the case of a long-term simulation, sequence length is defined on a yearly basis from January to December.

Maximum Number of Consecutive Shortages – maximum number of consecutive months with shortages that occurred during the simulation.

The following example illustrates the above definitions. The diversion shortages occurring during three 12-month simulation sequences are tabulated below and the metrics defined above are computed assuming these are the only sequences in the simulation. Sequence 1 has two short periods (January–March and December). Sequence 2 also has two shortage periods (January–March and June–October). The third sequence has only one shortage period.

Seq	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<u>Target (acre-feet)</u>												
1	2,733	2,649	2,775	2,901	3,447	4,414	4,667	4,457	4,204	3,742	3,111	2,901
2	2,733	2,649	2,775	2,901	3,447	4,414	4,667	4,457	4,204	3,742	3,111	2,901
3	2,733	2,649	2,775	2,901	3,447	4,414	4,667	4,457	4,204	3,742	3,111	2,901
<u>Shortage (acre-feet)</u>												
1	2,250	991	1,070	0	0	0	0	0	0	0	0	2,372
2	2,505	2,404	2,775	0	0	2,478	4,667	4,457	4,204	3,742	0	0
3	2,733	1,641	0	0	0	0	0	0	0	0	0	0

$$\text{maximum shortage} = 4,667 \text{ acre-feet}$$

$$\text{vulnerability} = \frac{2,372 + 4,667 + 2,733}{3} = 3,257 \text{ acre-feet}$$

$$\text{resiliency} = \frac{1}{\frac{3+1}{2} + \frac{3+5}{2} + \frac{2}{1}} = 0.375 \text{ months}$$

$$\text{average severity} =$$

$$\frac{\frac{2,250+991+1,070+2,372}{2} + \frac{2,505+2,404+2,775+2,478+4,667+4,457+4,204+3,742}{2} + \frac{2,733+1,641}{1}}{3} = 7,110.5 \text{ acre-feet}$$

$$\text{shortage index} = \frac{100}{36 \text{ months}} \sum \left(\left(\frac{\text{annual or sequence shortage}}{\text{annual or sequence target}} \right)^2 \right) = 15.22 \text{ months}^{-1}$$

$$\text{average number of failures per sequence} = \frac{2 + 2 + 1}{3} = 1.67$$

$$\text{maximum number of consecutive months with shortages} = 5 \text{ months}$$

Frequency Analyses

Exceedance frequency is an expression of the percentage-of-time or equivalently the likelihood or probability that a variable of interest will equal or exceed a certain amount. Exceedance frequency tables may be created with *TABLES* 2FRE and 2FRQ records for monthly *SIM* simulation results or 6FRE and 6FRQ records for *SIMD* simulation results. The tables may be based on considering all months or alternatively be developed for a specified month of the year such as May or August as specified by the parameter MON on the 2REL or 2FRQ record.

- naturalized flow, regulated flow, unappropriated flow, reservoir storage volume, and instream flow targets and shortages for specified control points
- instream flow quantities and reservoir storage volume for specified water rights
- reservoir storage volume and water surface elevation for specified reservoirs
- other variables such as reservoir draw-downs computed from these variables
- any simulation results variables or modifications thereof from a DATA record
- any variables read from any DSS file with DSSM, DSSD, or 7DSS records

Many or perhaps most applications of *TABLES* 2FRE and 2FRQ record frequency analysis capabilities deal with stream flows or reservoir storage without needing a DATA record. However, a DATA record allows 2FRE or 2FRQ frequency analyses to be performed for any of the variables in a *SIM* OUT or *SIMD* SUB output file or other daily, monthly, or annual time series developed by the DATA record from the simulation results.

Frequency analysis may be applied to moving averages or moving accumulative totals of the data computed for a user-specified number of months. The data may be adjusted by a multiplier factor, which may be a unit conversion factor or serve other purposes. The data may be added or subtracted from a constant. For example, the time series data for a frequency analysis of reservoir draw-downs is developed by subtracting water surface elevations from the inputted top of conservation pool elevation or storage volume may be subtracted from capacity. Likewise, deviations of regulated flows from a specified flow amount may be analyzed.

Table 7.13 illustrates the default standard format of a 2FRE frequency table. The 2FRE table includes the mean and standard deviation, minimum and maximum, and the flow or storage amounts that are equaled or exceeded specified percentages of the time. The 2FRE record also includes an option illustrated by Table 7.7 to write the frequencies and corresponding amounts as columns rather than rows. The alternative columnar several more frequencies.

The 2FRQ record also develops a frequency table for the same types of flow or storage variables, but in a different format illustrated by Table 7.14. The model-user enters specified flow or storage values of interest on the 2FRQ record. *TABLES* counts the number of months for which that specified amount was equaled or exceeded and applies Equation 7.3 to assign a frequency. The relative frequency counting method based on Equation 7.3 is the only option available for developing the 2FRQ frequency table. This method is also the default option for the 2FRE table. However, as discussed later, the 2FRE record also provides options for applying the normal (Gaussian) or log-normal probability distributions.

Tables 7.13 and 7.14 were created with the following TIN file input records.

```
2FRE 2
2FRQ 7 8 7 Whit 518.0 520.0 524.0 528.0 530.0 532.0 533.7
```

Table 7.13
2FRE Frequency Table from the Example in the *Fundamentals Manual*

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	41192.8	113873.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	47295.	107827.	1782162.
Whit	73082.2	178102.	0.0	0.0	0.0	0.0	0.0	0.0	0.	9804.	37467.	81772.	176914.	2977499.
WacoL	24957.5	59682.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	1440.	21230.	76616.	525736.
WacoG	127522.9	232813.	0.0	0.0	0.0	3562.0	10508.4	31264.1	45344.	62232.	76842.	117882.	290077.	3369010.
High	155825.2	268143.	0.0	0.0	0.0	6062.2	15834.9	39320.8	57559.	73507.	97585.	139127.	367260.	3588508.
Belton	28535.0	69015.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	1590.	20116.	95154.	538662.
George	3209.0	8113.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	821.	10538.	65371.
Grang	12617.0	25322.	0.0	0.0	0.0	0.0	0.0	0.0	0.	4.	2838.	11712.	42432.	199606.
Camer	88493.1	163314.	42.0	295.9	295.9	295.9	305.8	5565.2	16130.	27856.	47334.	101908.	225574.	1391574.
Bryan	272965.8	453299.	0.0	4930.6	12269.6	33842.6	49046.1	68963.0	98214.	112085.	130702.	274638.	634168.	4530216.
Hemp	301808.5	560894.	9205.5	9205.5	9863.0	9863.0	9863.0	10191.8	13757.	57774.	126749.	368095.	872073.	5463543.

Table 7.14
2FRQ Frequency Table from the Example in the *Fundamentals Manual*

WATER SURFACE ELEVATION-FREQUENCY FOR RESERVOIR Whit FOR MONTH 8

ELEVATION	FREQ(%)	ELEVATION	FREQ(%)	ELEVATION	FREQ(%)	ELEVATION	FREQ(%)	ELEVATION	FREQ(%)	ELEVATION	FREQ(%)	ELEVATION	FREQ(%)
518.0	100.00	520.0	96.10	524.0	79.22	528.0	70.13	530.0	51.95	532.0	25.97	533.7	18.18

Relative Frequency

Exceedance frequencies may be determined from the results of a *SIM* simulation based on counting the relative frequency in which various quantities are equaled or exceeded. Relative frequency is expressed by Eq. 7.3 where n is the number of months during the simulation that a particular flow or storage amount is equaled or exceeded, and N is the total number of months considered.

$$\text{Exceedance Frequency} = \frac{n}{N} (100\%) \quad (7.3)$$

The *Fundamentals Manual* example is based on a 77-year 1940–2016 hydrologic period-of-analysis. N is 924 months for Table 7.13 with all months considered in the frequency analysis. N is 77 months in Table 7.14 which was developed for the particular month of August.

In creating the 2FRE table for the predefined exceedance frequencies shown in the heading of Table 7.13, *TABLES* sorts and searches the flow or storage data to find a value that is equaled or exceeded during the specified percentage of the months. If a single monthly flow value does not precisely match that frequency, linear interpolation is applied to the two flow values that bracket the specified frequency. In developing the 2FRQ table for user-specified flow or storage

amounts, *TABLES* simply counts the number of months for which a specified amount (518 ft, 520 ft, 524 ft, 528 ft, 530 ft in Table 7.14) was equaled or exceeded. Table 7.14 reflects application of Equation 7.3 to the 77 values tabulated in the August column of Table 7.8.

Table 7.13 is frequency table for regulated stream flows based on considering all months. At the Bryan control point, the minimum and maximum regulated flow during the 696-month 1940-1997 simulation period is 0.0 and 4,521,903 acre-feet/month, respectively. The mean and standard deviation of regulated flows at the Bryan control point are 270,525 and 430,255 acre-feet/month, respectively. A flow of 14,093 ac-ft/month is equaled or exceeded during 98 percent of the 696 months of the hydrologic period-of-analysis. The regulated flow volume is at least 98,980 acre-feet during 60 percent of the 696 months. Thus, flows equal or exceed 98,980 ac-ft/month an estimated 60 percent of the time. The estimated probability that the flow volume at the Bryan control point will be at least 98,980 acre-feet in any randomly selected month is 0.60 for the water management and use scenario and modeling premises incorporated in the *SIM* simulation model and input dataset.

Normal and Log-Normal Probability Distributions

Alternatively, the *TABLES 2FRE* record provides options to apply the normal (Eq. 7.4) or log-normal (Eq. 7.5) probability distribution to the series of flow and storage amounts generated by *SIM* or adjustments thereto.

$$X = \bar{X} + z S \quad (7.4)$$

$$\log X = \overline{\log X} + z S_{\log X} \quad (7.5)$$

The frequency factor (z) is derived from a normal probability table. \bar{X} and S denote the mean and standard deviation of the data read from the *SIM* output file. $\overline{\log X}$ and $S_{\log X}$ are the mean and standard deviation of the logarithms of these data. The log-normal distribution consists of the normal distribution applied to the logarithms of X , with Eq. 7.4 expressed as Eq. 7.5 with z still derived from the normal probability distribution.

The random variable X in Equations 7.4 and 7.5 is the naturalized flows, regulated flows, unappropriated flows, instream flow shortages, reservoir storage volumes, or reservoir water surface elevations from the *SIM* simulation results or variations thereof reflecting adjustments made within *TABLES*. The mean \bar{X} and standard deviation S , computed from these data using Equations 7.6 and 7.7, are the parameters used to model frequency relationship as the log-normal or normal probability distributions.

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i \quad (7.6)$$

$$S = \left[\frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2 \right]^{0.5} \quad (7.7)$$

For the log-normal distribution, the mean $\overline{\log X}$ and standard deviation $S_{\log X}$ of the logarithms of the data from the *SIM* output file are computed and entered into Equation 7.5.

In the routines activated by the 2FRE record that apply the probability distribution options, exceedance probabilities are assigned to the random variable X by fitting the normal or log-normal distribution in the standard manner outlined in statistics books. The frequency factor z for specified exceedance frequencies tabulated in Table 7.15 are derived from the normal probability table and are built into *TABLES*. All of the frequencies listed in Table 7.15 are included if the results of the 2FRE frequency computations are tabulated in columnar format. With the standard row format illustrated earlier by Table 7.12, several of the frequencies are omitted to reduce the width of the table.

Table 7.15
Frequency Factors for the Normal Probability Distribution

Exceedance Frequency	Factor z in Eqs. 7.4 & 7.5	Exceedance Frequency	Factor z in Eqs. 7.4 & 7.5
99.9%	-3.09023	0.1%	3.09023
99.5%	-2.57583	0.5%	2.57583
99%	-2.32637	1%	2.32635
98%	-2.05377	2%	2.05375
95%	-1.64487	5%	1.64485
90%	-1.28156	10%	1.28156
80%	-0.84162	20%	0.84162
75%	-0.67450	25%	0.67450
70%	-0.52440	30%	0.52440
60%	-0.25335	40%	0.25335
50%	0.00000		

Choice of Alternative Frequency Analysis Computational Method

The 2FRE record choice between applying the concept of relative frequency directly using Eq. 7.3 versus adopting the normal (Eq. 7.4) or log-normal (Eq. 7.5) probability distributions depends upon the particular variable and application. When in doubt, the default relative frequency counting option based on Eq. 7.3 should probably be adopted. The normal or log-normal probability distribution functions offer potential improvements in the accuracy of the frequency estimates. One of the two alternative distributions should be considered for adoption if statistical goodness-of-fit tests made outside of WRAP demonstrates a reasonably close fit to the data. However, if the data do not closely fit either probability distribution function, Eq. 7.3 is the optimal choice of computation method.

A conventional frequency plot on normal probability paper of the data or logarithms of the data versus frequency calculated based on Eq. 7.3 provides a subjective measure of the closeness-of-fit of the probability distributions. If the normal or log-normal distribution accurately models the probability characteristics of the flow or storage variable of interest, the resulting frequency relationship will be close to the frequencies computed with Eq. 7.3 for a large sample size N , with the fit improving with increasing N .

The probability distributions perhaps may be more useful for frequency analyses for a particular month where the sample size N is only 1/12 of the size when considering all months. Conditional reliability modeling (CRM) is described in Chapter 8. The random variable is defined differently in CRM versus conventional simulations. The log-normal or normal distribution options perhaps may be more relevant for certain CRM applications.

The log-normal distribution allows the random variable to range from zero upward with no defined upper limit, which is consistent with stream flows. The normal distribution is symmetric about the mean with no lower and upper limits. The log-normal distribution will typically be a reasonably valid model for monthly naturalized stream flow volumes. Regulated and unappropriated flows are affected by water management practices that may invalidate application of the log-normal distribution. Storage capacity sets an upper limit on storage volumes that likely prevents proper fitting of either the normal or log-normal distributions, except perhaps for reservoirs that are never or seldom completely full or completely empty during the simulation. The distributions may be more appropriately applied to storage draw-downs rather than storage.

Frequency Analysis Variables

This manual and this chapter focus on monthly simulation results but also are relevant to daily simulation results. The daily WRAP system is covered in the *Daily Manual*.

The 2FRE and 2FRQ record frequency tables based on monthly quantities may be based on considering all months or alternatively be developed for a specified month of the year. Likewise, the 6FRE and 6FRQ record frequency analyses of daily quantities may be based on considering all days of the year or alternatively be developed for only those days falling within a specified month of the year such as March or July. 2FRE and 6FRE records include options for mathematically manipulating datasets prior to performing the frequency analysis computations.

In applying a 2FRE or 2FRQ record, *TABLES* reads monthly simulation results from the *SIM* or *SIMD* output OUT file. With a 6FRE or 6FRQ record, *TABLES* reads daily simulation results from the *SIMD* sub-monthly output SUB file. The *TABLES* DATA record reads all of the simulation results quantities from either a monthly OUT or daily SUB file and creates datasets to be analyzed with 2FRE, 6FRE, 2FRQ, 6FRQ, and time series records.

Most common applications of 2FRE/6FRE and 2FRQ/6FRQ frequency analyses deal with stream flows or reservoir storage without needing a DATA record. A DATA record allows 2FRE/6FRE/2FRQ/6FRQ frequency analyses to be performed for any of the variables in a *SIM* OUT or *SIMD* SUB output file or other daily, monthly, or annual time series developed by the DATA record from the simulation results. The 2FRE/6FRE and 2FRQ/6FRQ record routines can be applied to any data series created with DSSM, DSSD, or DATA records, which are introduced earlier in this chapter and further explained in Chapter 5 of the *Users Manual*.

The 37 time series record identifiers listed in Table 7.16 represent 32 time series variables read directly from the *SIM/SIMD* output OUT file or *SIMD* sub-monthly output SUB file and four other variables (CPI, DIV, IFS, IFF, RSD) computed within *TABLES* by combining simulation result variables. The variables are defined in Chapter 5 of this manual. The variables are associated with either control points, water rights, or reservoir/hydropower projects.

Frequency analyses can be performed directly with the 2FRE or 6FRE record for the variables marked with an asterisk in the first column of Table 7.16 without needing a DATA record. (The integers in parenthesis with the * are the variable identifiers in 2FRE/6FRE field 2.) All of the simulation results time series variables from the *SIM* output OUT or *SIMD* SUB output files listed in Table 7.16 can be read with a DATA record and manipulated to create other datasets consisting of daily or monthly quantities or annual totals, minima, or maxima covering a specified number of time periods defining a season of the year. Moving averages or totals may be adopted. The 2FRE or 6FRE routines can be applied to the resulting time series datasets.

Table 7.16
SIM and *SIMD* Simulation Results Variables

Variable from Simulation Results	Time Series ID	Simulation Results for Specified		
		Control Point	Water Right	Reservoir
naturalized stream flow (*1)	NAT	control point		
regulated stream flow (*2)	REG	control point		
unappropriated stream flow (*3)	UNA	control point		
channel loss	CLO	control point		
channel loss credit	CLC	control point		
return flow returned this control point	RFR	control point		
upstream reservoir release	URR	control point		
control point inflow	CPI	control point		
reservoir storage (*4,5,6)	STO	control point	water right	reservoir
evaporation-precipitation volume	EVA	control point	water right	reservoir
stream flow depletion	DEP	control point	water right	
diversion target	TAR	control point	water right	
diversion shortage	SHT	control point	water right	
diversion	DIV	control point	water right	
hydroelectric energy target	TAR		water right	
hydroelectric energy shortage	SHT		water right	
firm energy produced	DIV		water right	
instream flow target (*8,11)	IFT	control point	water right	
instream flow shortage (*9,12)	IFS	control point	water right	
instream flow target supplied (*10,13)	IFF			
flow switch record volume	FSV		water right	
flow switch record count	FSC		water right	
return flow for water right	RFL		water right	
available stream flow	ASF		water right	
increase in available flow	XAV		water right	
secondary reservoir release	ROR		water right	
hydropower shortage	HPS			reservoir
electric energy generated	HPE			reservoir
stream flow depletions	RID			reservoir
inflows from reservoirs	RIR			reservoir
releases useable for power	RAH			reservoir
releases not accessible	RNA			reservoir
adjusted evaporation-precip depth	EPD			reservoir
evaporation-precipitation depth	EVR			reservoir
water surface elevation (*7)	WSE			reservoir
reservoir storage capacity	RSC			reservoir
reservoir drawdown volume	RSD			reservoir

* Variable identifiers in 2FRE and 6FRE record field 2.

Flood Frequency Analyses

The *TABLES* 7FFA record routines are designed specifically for flood frequency analyses of daily *SIMD* simulation results. *HEC-SSP* will reproduce the basic flood frequency analysis results developed with the *TABLES* 7FFA record and also provide additional auxiliary information that is not provided by *TABLES*, including confidence limits and frequency plots. Examples illustrating the *TABLES* 7FFA record routine and *HEC-SSP* are found in Chapter 9 of the *Daily Manual*. Other tables created by *TABLES* to organize simulation results are generally applicable either with or without flood control being considered and may be adopted along with 7FFA record tables to organize the results of a simulation study of flood control operations. The 7FFA record is used only with peak annual flows and storage recorded in a *SIMD* output AFF file. The *TABLES* 7DSS record performs the same computations as the 7FFA record for any annual data series stored in a DSS file.

SIMD has an option, activated by parameter AFF on the *JT* record, to write annual series of maximum naturalized flows, regulated flows, reservoir storages, and excess flows (defined below) to an output file with the filename extension AFF. The peak daily flow and storage volumes are listed for each year of the *SIMD* simulation at specified control points. These series of annual peak daily volumes are input data for the 7FFA record routines. The organization of the *SIMD* AFF file read by *TABLES* is described in Table 7.17. Peak annual series may be generated for all or selected control points. If reservoir storage is not associated with a control point in the AFF output file, a value of -1.0 is inserted in the storage column.

Table 7.17
Organization of the *SIMD* Annual Flood Frequency AFF Output File

First record is the following heading: WRAP-SIMD Flood Frequency Analysis File

Second record contains values for the variables total number of years *NYRS* and total number of control points *NCPTS*.

Third record is the column headings for the data to follow:

YEAR CPID NAT-FLOW REG-FLOW STORAGE EXCESS FLOW

Annual listing with each line containing the year, control point, and maximum values of naturalized flow, regulated flow, and reservoir storage volume occurring in each year.

A parameter on the 7FFA record allows the user to select the annual data series from the AFF file for which the frequency analysis is applied. The options are (1) maximum daily naturalized flow, (2) maximum daily regulated flow, (3) maximum daily storage contents, and (4) summation of maximum daily storage contents and total annual excess flow volume.

Adjustments to Remove Non-Homogeneity of Exceeding Controlled Storage Capacity

The excess flow volume in the last column of the *SIMD* AFF file (Table 7.17 above) is used within the *TABLES* 7FFA record frequency analysis routine to deal with the following complexity. A dataset of maximum annual reservoir storage contents is subject to non-

homogeneity associated with switching between regular and emergency reservoir operations that invalidates a frequency analysis. Thus, the frequency analysis is applied to the summation of peak annual storage volume plus corresponding excess flow volume as described below.

The exceedance probability, exceedance frequency, or recurrence interval associated with filling the controlled flood control pool are meaningful measures of the flood control capacity of a reservoir. Storage-frequency relationships for the full range of flood levels also provide useful information. However, the validity of a frequency analysis is affected by the change from regular to emergency reservoir operations that occurs whenever the controlled flood control storage capacity is exceeded. Emergency operations may be modeled in *SIMD* simply by allowing outflow to equal inflow whenever the controlled flood control pool storage capacity is exceeded. Alternatively, *FV/FQ* records may be used to model surcharge storage. In either case, the non-homogeneity associated with switching between regular (*FF* record) and emergency surcharge (*FV/FQ* record) flood control operations invalidates the application of the log-Pearson III analysis directly to storage volumes. Thus, the excess flows are used to adjust the storage.

The excess flow volume tabulated in the last column of the AFF file is the total flow from the reservoir in a year that occurs during days in which the controlled flood control capacity is exceeded. These are uncontrolled spills from the surcharge pool of a full reservoir. The excess flow volume for the year is zero in years during which the controlled flood control capacity is not exceeded, which is typically most years or perhaps all years of the simulation for major flood control reservoirs. Adding the excess flow volume to the reservoir storage capacity approximates the storage contents that would have occurred in a reservoir with a controlled flood control pool that is infinitely large or at least large enough to not be overtopped during the hydrologic period-of-analysis of the simulation.

Log-Pearson Type III Model of Annual Peak Flow and Storage

The 7FFA record builds a table of daily flow or storage volumes corresponding to annual exceedance frequencies of 99, 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent, which correspond to recurrence intervals of 1.01, 2, 5, 10, 25, 50, 100, 200, and 500 years. The relationship between annual exceedance probability *P* and recurrence interval *T* in years is:

$$T = \frac{1}{P} \quad \text{or} \quad P = \frac{1}{T} \quad (7.8)$$

The flood frequency analysis computations are based on applying the log-Pearson type III probability distribution in a standard manner outlined by many textbooks and the Interagency Advisory Committee on Water Data [27]. The frequency factor table is reproduced as Table 7.17. The random variable *X* is the maximum daily (or other time period) naturalized flow, regulated flow, or end-of-period reservoir storage volume to occur in a year. The *X* corresponding to a given exceedance probability is determined from Equation 7.9 combined with a table relating the frequency factor *K* to exceedance probability *P* and skew coefficient *G*.

$$\log X = \overline{\log X} + K S_{\log X} \quad (7.9)$$

The mean $\overline{\log X}$, standard deviation $S_{\log X}$, and skew coefficient $G_{\log X}$ of the logarithms of *X* are computed from an annual series of maximum daily flow or storage volumes *X*. The mean and

standard deviation are computed with Equations 7.6 and 7.7. The skew coefficient is computed with Equation 7.10. The frequency factor K is obtained as a function of P and $G_{\log X}$ by linear interpolation of a Pearson type III probability table built into the program *TABLES*. The probability table in *TABLES* is more precise with more digits than shown in Table 7.18.

Table 7.18
Frequency Factor K for the Pearson Type III Distribution

Skew Coef G	Recurrence Interval (years)							
	1.01	2	5	10	25	50	100	200
	Exceedance Frequency (percent)							
	99	50	20	10	4	2	1	0.5
3.0	-0.667	-0.396	0.420	1.180	2.278	3.152	4.051	4.970
2.8	-0.714	-0.384	0.460	1.210	2.275	3.114	3.973	4.847
2.6	-0.769	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.4	-0.832	-0.351	0.537	1.262	2.256	3.023	3.800	4.584
2.2	-0.905	-0.330	0.574	1.284	2.240	2.970	3.705	4.444
2.0	-0.990	-0.307	0.609	1.302	2.219	2.912	3.605	4.398
1.8	-1.087	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.6	-1.197	-0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.4	-1.138	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.2	-1.449	-0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.0	-1.588	-0.164	0.758	1.340	2.043	2.542	3.022	3.489
0.8	-1.733	-0.132	0.780	1.336	1.993	2.453	2.891	3.312
0.6	-1.880	-0.099	0.800	1.328	1.939	2.359	2.755	3.132
0.4	-2.029	-0.066	0.816	1.317	1.880	2.261	2.615	2.949
0.2	-2.178	-0.033	0.830	1.301	1.818	2.159	2.472	2.763
0.0	-2.326	0.000	0.842	1.282	1.751	2.054	2.326	2.576
-0.2	-2.472	0.033	0.850	1.258	1.680	1.945	2.178	2.388
-0.4	-2.615	0.066	0.855	1.231	1.606	1.834	2.029	2.201
-0.6	-2.755	0.099	0.857	1.200	1.528	1.720	1.880	2.016
-0.8	-2.891	0.132	0.856	1.166	1.448	1.606	1.733	1.837
-1.0	-3.022	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.2	-3.149	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.4	-3.271	0.225	0.832	1.041	1.198	1.270	1.318	1.351
-1.6	-3.388	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.8	-3.499	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-2.0	-3.605	0.307	0.777	0.895	0.959	0.980	0.990	0.995
-2.2	-3.705	0.330	0.752	0.844	0.888	0.900	0.905	0.907
-2.4	-3.800	0.351	0.725	0.795	0.823	0.830	0.832	0.833
-2.6	-3.899	0.368	0.696	0.747	0.764	0.768	0.769	0.769
-2.8	-3.973	0.384	0.666	0.702	0.712	0.714	0.714	0.714
-3.0	-4.051	0.396	0.636	0.660	0.666	0.666	0.667	0.667

$$G = \frac{n \sum_{i=1}^n (X_i - \bar{X})^3}{(n-1)(n-2) S^3} \quad (7.10)$$

The frequency table created by the 7FFA record also includes the expected value of the flow or storage. The expected value is a probability-weighted average.

Log-Normal Probability Distribution

With a skew coefficient value of zero, the log-Pearson type III distribution is identical to the log-normal probability distribution. The values for K in Table 7.18 for a G of zero are the same as the values from normal probability tables. Thus, a frequency analysis based on the log-normal distribution may be performed with *TABLES* by specifying a skew coefficient of zero on the 7FFA record.

The log-normal probability distribution is applied extensively in modeling hydrologic variables. The log-normal distribution is equivalent to applying the normal (Gaussian) probability distribution to the logarithm of the random variable. Unlike the normal distribution, the log-normal and log-Pearson III distributions assign non-zero probabilities to only ranges of positive values of the random variable. With the log-normal or log-Pearson III distribution, the random variable has a probability of zero of being less than zero, which is appropriate for many variables including stream flow and reservoir storage.

The log-normal probability distribution has only two parameters, the mean and standard deviation. The log-Pearson type III distribution provides greater flexibility than the log-normal in that a third parameter, the skew coefficient, allows the skewness of the probability density function to be adjusted. However, as discussed in the next section, the accuracy of estimates of the skew coefficient is significantly limited by sample size.

Skew Coefficient

The skew coefficient G computed with Eq. 7.10 is particularly sensitive to extreme flood events due to the cube term. Estimates from small samples may be inaccurate. Thus, Bulletin 17B and Bulletin 17C [31, 32] provides a generalized skew map for flood flows that is reproduced by various other references [41]. Depending on the number of years of gage record, regionalized skew coefficients are used either in lieu of or in combination with values computed from observed flows at the location of concern.

Equations 7.11-7.16 allow a weighted skew coefficient G_w for flood flows to be computed by combining a regionalized skew coefficient G_R and station skew coefficient G [41].

$$G_w = \frac{(MSE_R)(G) + (MSE_S)(G_R)}{MSE_R + MSE_S} \quad (7.11)$$

$$MSE_S = 10^{[A - B(\text{Log}_{10}(N/10))]} \quad (7.12)$$

$$A = -0.33 + 0.08|G| \quad \text{if } |G| \leq 0.90 \quad (7.13)$$

$$A = -0.52 + 0.30|G| \quad \text{if } |G| > 0.90 \quad (7.14)$$

$$B = 0.94 - 0.26|G| \quad \text{if } |G| \leq 1.50 \quad (7.15)$$

$$B = 0.55 \quad \text{if } |G| > 1.50 \quad (7.16)$$

The station skew G is computed from the logarithms of the observed flows using Eq. 7.10. The

regional skew G_R is either developed from multiple stations following procedures outlined in Bulletin 17B or read from the generalized skew coefficient map also supplied by Bulletin 17B. The generalized regional skew coefficients G_R are for the logarithms of annual maximum stream flow. MSE_S denotes the mean square error of the station skew. MSE_R is the mean square error of the regional skew. Bulletin 17B sets the MSE_R at 0.302 if G_R is taken from the generalized skew map.

The 7FFA record in *TABLES* provides options for determining the skew coefficient G for the logarithms of the annual peak naturalized and regulated flow and storage volumes. By default, the program computes G with Eq. 6.13. Alternatively, G may be computed external to the program and entered as input. As another option, the regionalized skew coefficient G_R may be entered as input and combined with G internally within the program based on Eqs. 6.13-6.18 to determine a weighted skew coefficient G_w . The program uses a MSE_R of 0.302 from Bulletin 17B.

Listing of Annual Peaks with Weibull Probabilities

The 7FFA record will also create a tabulation of peak annual naturalized and regulated flows and reservoir storage with exceedance frequencies assigned by the Weibull formula.

$$P = \frac{m}{N+1} \quad (7.17)$$

where P denotes annual exceedance probability, m is the rank of the values ($m = 1, 2, 3, \dots, N$), and N is the total number of years in the data series. The greatest flow or storage volume is assigned a rank (m) of 1, and the smallest is assigned a rank of N .

HEC-SSP Statistical Software Package

The *HEC-SSP Statistical Software Package* [30] performs flood frequency analyses as outlined above and will reproduce the results obtained with the *TABLES* 7FFA record routine. HEC-SSP also computes confidence limits, and expected probability adjustments, and frequency plots which are not provided with the 7FFA record. The *HEC-SSP* software and user's manual are available for download from the Hydrologic Engineering Center website.

Economic Flood Damages

The frequency table developed with *TABLES* is expanded to a frequency and damage table with addition of 7VOL and 7DAM records following the 7FFA record. 7VOL and 7DAM records provide a table of daily stream flow or reservoir storage volume versus damage. The 7DAM record contains flood damages in dollars (or other units) corresponding to the stream flow or storage volumes on the 7VOL record. Economic flood damages in dollars are normally entered on a 7DAM record. However, the damage function may be generically treated as a penalty function with other devised units. *TABLES* assigns damages to the volumes in the frequency table by linear interpolation of the 7VOL/7DAM record table. The resulting table includes the volume and damage for each frequency and also average annual damages.

Average annual damage or the expected value of annual damages, in dollars, is a probability-weighted average of the full range of possible of possible flood magnitudes. Flood damages in different years may range from none to catastrophic. The *average annual damage*

represents the average that might be expected to occur over an extremely large number of years or the damages that may be expected to occur, on average, in any future year. The terms *expected* and *average* annual damage are used interchangeably. The expected value of annual damage is determined by numerical integration of the exceedance frequency versus damage relationship. The methodology outlined in "Section 11.3 Simulation of Flood Damage Reduction Systems" of the textbook by Wurbs and James [31] is incorporated into *TABLES*.

The expected value of both the flow volume or storage and the damages are included in the table determined using the same numerical integration algorithm. The expected value of flow volume or storage is included in the 7FFA record frequency analysis table even if the 7VOL/7DAM record economic analysis is not activated.

Reservoir Contents, Drawdown Duration, and Storage Reliability

Reservoir storage frequency tables may be developed using 2FRE or 2FRQ records for either water rights, control points, or reservoirs as discussed in the preceding section. The 2RES record provides an alternative format for storage frequency analyses based on storage volumes from reservoir/ hydropower output records. The 2RES record results in three tables for selected reservoirs:

1. storage contents as a percentage of storage capacity
2. drawdown-duration relationships
3. storage-reliability relationships

The following *TABLES* input TIN file records were employed to create the tables reproduced as Tables 7.19, 7.20, and 7.21. Input records are explained in the *Users Manual*.

2RES	0	0	6	PK	Whit	WacoL	Belton	George	Grang
2RES				570240.	627100.	192100.	457600.	37100.	65500.
2RES				0.	379000.	580.	0.	240.	220.

The first table is a tabulation of end-of-month storage content expressed as a percentage of the storage capacity of a user-specified zone. The storage content as a percentage is

$$\text{storage content as percentage of capacity} = \frac{S - C_2}{C_1 - C_2} (100\%) \quad (7.18)$$

where C_1 and C_2 are the user-specified total storage capacity below the water surface elevations defining the top and bottom of the storage zone or pool being considered. Often C_1 will be the total conservation storage capacity and C_2 will be entered as zero. C_1 may be the total conservation capacity, and C_2 the inactive storage capacity. Other zones may be analyzed as well. The storage percentage is negative for a storage content less than C_2 and greater than 100% for a storage content greater than C_1 . The table format is illustrated by Table 7.19 which shows only the first 20 months of the 924 months included in the table. This type of table is designed for comparing storage in the different reservoirs of a system.

The 2RES drawdown-duration table illustrated by Table 7.20 shows the number of months of the simulation for which the end-of-month drawdown exceeds given percentages of the storage

capacity of the specified storage zone. Drawdowns are expressed as a percentage of storage capacity as follows. The terms in Eq. 7.19 are defined the same as in Eq. 7.18.

$$\text{drawdown as percentage of capacity} = 100\% - \frac{S - C_2}{C_1 - C_2}(100\%) \quad (7.19)$$

Table 7.19
Beginning of Table of Reservoir Storage Content as a Percentage of Capacity

END-OF-PERIOD RESERVOIR STORAGE AS A PERCENTAGE OF CAPACITY

Percentage = 100% * (S - C2) / (C1 - C2) where
S = end-of-month storage
C1,C2 = user defined top and bottom of storage zone

YEAR	MONTH	MEAN	PK	Whit	WacoL	Belton	George	Grang
1940	1	95.49	87.31	99.44	97.53	96.27	95.46	96.93
1940	2	93.23	86.27	88.84	95.63	94.31	94.95	99.36
1940	3	77.31	82.16	76.30	92.08	91.05	90.75	31.53
1940	4	81.75	80.95	76.02	100.00	94.51	96.80	42.20
1940	5	85.34	96.14	73.19	95.51	91.71	100.00	55.47
1940	6	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1940	7	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1940	8	94.05	100.00	100.00	92.61	95.86	94.13	81.68
1940	9	87.87	87.04	100.00	87.66	89.41	86.84	76.26
1940	10	80.65	82.59	87.94	83.89	71.65	84.41	73.40
1940	11	98.95	93.67	100.00	100.00	100.00	100.00	100.00
1940	12	99.93	99.58	100.00	100.00	100.00	100.00	100.00
1941	1	99.75	98.50	100.00	100.00	100.00	100.00	100.00
1941	2	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1941	3	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1941	4	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1941	5	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1941	6	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1941	7	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1941	8	98.58	100.00	100.00	100.00	100.00	94.73	96.76

Table 7.20
Reservoir Storage Drawdown Duration Table

RESERVOIR STORAGE DRAWDOWN DURATION

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	NUMBER OF PERIODS WITH DRAWDOWNS EQUALING OR EXCEEDING PERCENT OF ZONE STORAGE CAPACITY								
				0%	2%	5%	10%	25%	50%	75%	90%	100%
PK	356702.97	0.	570240.	924.	747.	708.	654.	508.	302.	167.	117.	67.
Whit	537820.56	379000.	627100.	924.	619.	595.	562.	465.	303.	192.	139.	101.
WacoL	173501.89	580.	192100.	924.	507.	434.	321.	112.	21.	0.	0.	0.
Belton	270598.38	0.	457600.	924.	720.	694.	644.	527.	371.	222.	125.	82.
George	19113.99	240.	37100.	924.	719.	691.	639.	553.	430.	353.	283.	214.
Grang	37964.90	220.	65500.	924.	621.	598.	565.	501.	390.	274.	201.	147.

TABLES counts and tabulates the number of months during the simulation for which the draw-down defined by Equation 7.19 equals or exceeds 0%, 2%, 5%, 10%, 25%, 50%, 75%, 90%, and 100% of the storage capacity defined by Equation 7.18. For example in Table 7.20, for Possum Kingdom Reservoir (identifier PK), the drawdown is at least 10 percent of the specified storage capacity during 654 months of the 724-month 1940-2016 hydrologic period-of-analysis.

Alternatively, the storage-reliability table illustrated by Table 7.21 shows the frequency that specified storage levels are equaled or exceeded. Possum Kingdom Reservoir (PK) is full at 100 percent capacity during 16.0 percent of the months of the 924 month simulation. Storage in PK equals or exceeds 95 percent of capacity defined by Equation 7.18 during 23.4 percent of the 924 months. PK is at least 75 percent full 45.0 percent of the time for the scenario modeled.

Table 7.21
Reservoir Storage Reliability Table

RESERVOIR STORAGE RELIABILITY

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING								
				PERCENTAGE OF STORAGE CAPACITY								
				100%	98%	95%	90%	75%	50%	25%	10%	>0%
PK	356702.97	0.	570240.	16.0	19.2	23.4	29.2	45.0	67.3	81.9	87.3	100.0
Whit	537820.56	379000.	627100.	31.3	33.0	35.6	39.2	49.7	67.2	79.2	85.0	95.1
WacoL	173501.89	580.	192100.	40.0	45.1	53.0	65.3	87.9	97.7	100.0	100.0	100.0
Belton	270598.38	0.	457600.	19.5	22.1	24.9	30.3	43.0	59.8	76.0	86.5	100.0
George	19113.99	240.	37100.	20.2	22.2	25.2	30.8	40.2	53.5	61.8	69.4	76.8
Grang	37964.90	220.	65500.	31.0	32.8	35.3	38.9	45.8	57.8	70.3	78.2	84.1

Summary Tables

Overview summaries of simulation results created by 2SBA, 2SCP, 2SWR, 2SGP, and 2SRE record routines consist of either a monthly or annual tabulation of selected data items contained on the *SIM* control point, water right, or reservoir/hydropower output records. A monthly table has an additional column for the month and 12 times as many rows as an annual table.

A 2SBA record results in a basin(s) summary table reflecting the entire dataset. The naturalized, regulated, and unappropriated stream flows in the 2SBA table are the maximum of the values found at any of the control points. The other tabulated data are the summation of values for all of the control points.

A 2SCP record instructs *TABLES* to create a summary table for each of any number of control points. Table 7.22 is an annual summary table for a selected control point from the example. The corresponding monthly summary table would be 12 times as long. Naturalized, unappropriated, and regulated flows are defined for control points. The stream flow depletions, diversions, and diversion shortages are the summations for all water rights at the control point. End-of-period storage and net evaporation-precipitation are totals for all reservoirs, though typically no more than one reservoir will be assigned to a control point. Table 7.22 was created with the following input record.

2SCP 0 1 WacoL

Table 7.22
Summary Table for a Control Point

ANNUAL SUMMARY TABLE FOR CONTROL POINT WacoL

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1940	371606.0	275650.3	275650.3	0.0	95955.7	192100.0	15155.7	80800.0	0.0
1941	786143.0	701302.2	701302.2	0.0	84840.7	181607.3	14533.4	80800.0	0.0
1942	807665.0	700654.7	699331.7	0.0	107010.3	192100.0	15717.5	80800.0	0.0
1943	86189.0	26167.4	26167.4	0.0	60021.6	145496.8	25824.9	80800.0	0.0
1944	484119.0	372479.5	372479.5	0.0	111639.5	159871.5	16464.8	80800.0	0.0
1945	839250.0	712471.5	712471.5	0.0	126778.5	192100.0	13750.0	80800.0	0.0
1946	319845.0	259620.6	259620.6	0.0	60224.4	153352.9	18171.4	80800.0	0.0
1947	222143.0	129949.1	129949.1	0.0	92193.9	139705.7	25041.1	80800.0	0.0
1948	92400.0	0.0	0.0	0.0	92400.0	123533.8	27771.9	80800.0	0.0
1949	197405.0	53664.8	53664.8	0.0	143740.2	167408.9	19065.1	80800.0	0.0
1950	104406.0	2554.1	2554.1	0.0	101851.9	163543.6	24917.2	80800.0	0.0
1951	56302.0	0.0	0.0	0.0	56302.0	109442.3	29603.3	80800.0	0.0
1952	146643.0	0.0	0.0	0.0	146643.0	149924.6	25360.7	80800.0	0.0
1953	208278.0	116586.3	116586.3	0.0	91691.7	140860.3	19956.0	80800.0	0.0
1954	77612.0	4448.6	0.0	0.0	73163.4	105132.8	28090.9	80800.0	0.0
1955	85964.0	0.0	0.0	0.0	85964.0	95302.7	14994.2	80800.0	0.0
1956	84638.0	0.0	0.0	0.0	84638.0	74271.0	24869.7	80800.0	0.0
1957	810381.0	610614.2	610614.2	0.0	199766.8	192100.0	1137.8	80800.0	0.0
1958	358209.0	283023.5	278010.3	0.0	75185.5	174362.7	12122.8	80800.0	0.0
1959	430167.0	324987.7	324987.7	0.0	105179.3	192100.0	6642.0	80800.0	0.0
1960	332707.0	239038.8	239038.8	0.0	93668.2	192100.0	12868.2	80800.0	0.0
1961	905330.0	815859.1	810759.9	0.0	89470.9	192100.0	8670.9	80800.0	0.0
1962	114884.0	32759.2	32759.2	0.0	82124.8	175314.9	18109.8	80800.0	0.0
1963	31304.0	0.0	0.0	0.0	31304.0	102493.9	23325.0	80800.0	0.0
1964	231187.0	45017.7	36594.9	0.0	186169.3	192100.0	15763.3	80800.0	0.0
1965	628020.0	537758.1	537758.1	0.0	90261.9	192100.0	9461.9	80800.0	0.0
1966	365306.0	284372.5	284372.5	0.0	80933.5	179192.3	13041.2	80800.0	0.0
1967	93176.0	0.0	0.0	0.0	93176.0	173417.2	18151.1	80800.0	0.0
1968	866935.0	760659.9	760659.9	0.0	106275.1	192100.0	6792.3	80800.0	0.0
1969	335551.0	240159.5	240159.5	0.0	95391.5	192100.0	14591.5	80800.0	0.0
The lines of data for 1970 through 1999 are deleted to shorten the table.									
2000	539791.1	397928.2	397928.2	0.0	141862.9	192100.0	12933.7	80800.0	0.0
2001	420518.0	329420.8	325183.9	0.0	91097.2	192100.0	10297.2	80800.0	0.0
2002	323197.4	229684.0	228520.9	0.0	93513.4	192100.0	12713.4	80800.0	0.0
2003	285442.0	193856.1	193856.1	0.0	91585.9	186019.5	16866.4	80800.0	0.0
2004	1020179.1	933678.6	933678.6	0.0	86500.5	192100.0	-380.0	80800.0	0.0
2005	181984.6	106624.7	106624.7	0.0	75359.9	163420.3	23239.7	80800.0	0.0
2006	109028.5	0.0	0.0	0.0	109028.5	170365.9	21282.8	80800.0	0.0
2007	1481037.5	1383674.5	1383674.5	0.0	97363.1	187449.7	-520.7	80800.0	0.0
2008	131527.6	68911.1	68911.1	0.0	62616.6	147789.6	21476.7	80800.0	0.0
2009	812833.0	676738.8	676738.8	0.0	136094.3	192100.0	10983.8	80800.0	0.0
2010	434480.5	352040.8	345869.5	0.0	82439.8	178134.4	15605.3	80800.0	0.0
2011	150561.2	24678.2	13830.7	0.0	125883.1	192100.0	31117.5	80800.0	0.0
2012	451387.9	386255.7	379823.4	0.0	65132.1	159184.9	17247.1	80800.0	0.0
2013	412487.5	284119.6	257317.3	0.0	128367.9	192100.0	14652.8	80800.0	0.0
2014	228135.0	131847.5	131847.5	0.0	96287.5	187668.0	19919.5	80800.0	0.0
2015	1501898.4	1413967.1	1413967.1	0.0	87931.2	192100.0	2699.2	80800.0	0.0
2016	698304.5	605590.8	603051.8	0.0	92713.6	192100.0	11913.5	80800.0	0.0
MEAN	395299.1	299490.5	295742.9	0.0	95808.6	169849.8	15008.5	80800.0	0.0

Likewise, 2SWR and 2SRE records create summary tables for specified water rights or reservoirs. A 2SGP record results in a summation of certain data on the SIM water right output records of multiple rights with the same group identifier in fields 12 or 13 of the WR input records. The water right group summary table has the summation of the stream flow depletions, diversions, and diversion shortages associated with all water rights with the specified group identifier.

Water Budget Tables

A 2BUD record develops two types of tables.

1. A monthly water budget tabulation may be created for a selected control point or all control points for each month of the simulation. This is a very lengthy tabulation.
2. A river basin water budget is a very concise summary table aggregating data computed for all individual control points and all months into period-of-analysis basin totals.

Monthly computations are performed for all control points in developing the 2BUD total river basin water budget table. The 2SBA, 2SCP, 2SWR, 2SGP, and 2SRE summary tables described above tabulate *SIM* simulation results with only minor additional computations. The 2BUD routine uses *SIM* input and output data in relatively extensive computations which are required to develop all components of a complete water budget. The water budgets are tabulations of the individual components of inflows to and outflows from the control point or river basin along with changes in reservoir storage. The following water budget equation is confirmed.

$$\text{sum of all inflows} - \text{sum of all outflows} = \text{change in storage}$$

The water budget routines were initially developed with the program *SALT*. The detailed accounting of inflow and outflow components is required for tracking salt loads and concentrations through the system. The water budget routines within *SALT* are an integral part of the simulation. The same basic computations are consolidated into the *TABLES* 2BUD record routine. The two types of tables created by the 2BUD record have general utility in analyzing simulation results.

The *TABLES* 2BUD water budget computations are based on reading the simulation results from a *SIM* output OUT file containing output records for all control points included in the *SIM* DAT file. Additional information is also read from the *SIM* DAT file. Two different types of water budget tables may be developed, river basin and individual control point. Computations are performed for all control points in the process of developing the river basin water budget table. Results associated with individual control points are recorded in the individual control point water budget table. The computations step sequentially through time and, for each month, are performed by control point in upstream-to-downstream order. Either the control point *CP* records must be in upstream-to-downstream order in the *SIM* input DAT file or a *TABLES* input 1CPT record must be used to with the 2BUD record to rearrange the control point sequencing.

Table 7.23 shows the first 24 months of a water budget table for the Waco Lake control point. The entire tabulation is 924 months long. Table 7.24 is the complete water budget summary table for the entire river basin for the entire hydrologic period-of-analysis. Tables 7.23 and 7.24 are created with the following input records.

```

2BUD   WacoL           1       1   -1
2BUD                                     1

```

The variables in the control point water budget tabulation and the river basin summary water budget table are defined in Tables 7.25 and 7.26, respectively. The variable names used in the Fortran code are adopted in Tables 7.25 and 7.26 and the following discussion.

Table 7.23
Beginning (First two Years) of 1940-2016 Monthly Control Point Water Budget Tabulation

YEAR	M	CPID	NAT(CP)	CLC(CP)	CL(CP)	INAT	EBEG	RET(CP)	CINF	FCLC	FCL	REG(CP)	DIV	KOIH	EMAP(CP)	BSD(CP)	SID(CP)	XSID	XSUM
1940	1	WaccoL	1166.	0.	0.	1166.	0.	0.	0.	0.	0.	0.	5252.	0.	642.	192100.	187372.	-4728.	-4728.
1940	2	WaccoL	1315.	0.	0.	1315.	0.	0.	0.	0.	0.	0.	5090.	0.	-136.	187372.	183733.	-3639.	-3639.
1940	3	WaccoL	1182.	0.	0.	1182.	0.	0.	0.	0.	0.	0.	5494.	-0.	2492.	183733.	176928.	-6805.	-6805.
1940	4	WaccoL	36755.	0.	0.	36755.	0.	0.	0.	0.	0.	16373.	5818.	0.	-608.	176928.	192100.	15172.	15172.
1940	5	WaccoL	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	6868.	0.	1729.	192100.	183503.	-8597.	-8597.
1940	6	WaccoL	61991.	0.	0.	61991.	0.	0.	0.	0.	0.	46130.	7514.	-0.	-250.	183503.	192100.	8597.	8597.
1940	7	WaccoL	41936.	0.	0.	41936.	0.	0.	0.	0.	0.	28939.	9534.	0.	3463.	192100.	192100.	0.	-0.
1940	8	WaccoL	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9211.	0.	4932.	192100.	177957.	-14143.	-14143.
1940	9	WaccoL	2999.	0.	0.	2999.	0.	0.	0.	0.	0.	0.	7676.	0.	4808.	177957.	168471.	-9485.	-9485.
1940	10	WaccoL	2477.	0.	0.	2477.	0.	0.	0.	0.	0.	0.	7030.	-0.	2675.	168471.	161244.	-7228.	-7228.
1940	11	WaccoL	93211.	0.	0.	93211.	0.	0.	0.	0.	0.	60219.	5737.	-0.	-3601.	161244.	192100.	30856.	30856.
1940	12	WaccoL	128574.	0.	0.	128574.	0.	0.	0.	0.	0.	123989.	5575.	0.	-991.	192100.	192100.	0.	0.
1941	1	WaccoL	45901.	0.	0.	45901.	0.	0.	0.	0.	0.	39994.	5252.	0.	655.	192100.	192100.	0.	0.
1941	2	WaccoL	129987.	0.	0.	129987.	0.	0.	0.	0.	0.	125985.	5090.	0.	-1089.	192100.	192100.	0.	-0.
1941	3	WaccoL	94948.	0.	0.	94948.	0.	0.	0.	0.	0.	89233.	5494.	-0.	221.	192100.	192100.	0.	0.
1941	4	WaccoL	133705.	0.	0.	133705.	0.	0.	0.	0.	0.	128068.	5818.	0.	-180.	192100.	192100.	0.	-0.
1941	5	WaccoL	174943.	0.	0.	174943.	0.	0.	0.	0.	0.	167328.	6868.	0.	647.	192100.	192100.	0.	0.
1941	6	WaccoL	76423.	0.	0.	76423.	0.	0.	0.	0.	0.	68827.	7514.	0.	82.	192100.	192100.	0.	0.
1941	7	WaccoL	61285.	0.	0.	61285.	0.	0.	0.	0.	0.	48189.	9534.	0.	3561.	192100.	192100.	0.	-0.
1941	8	WaccoL	46901.	0.	0.	46901.	0.	0.	0.	0.	0.	33678.	9211.	-0.	4011.	192100.	192100.	0.	0.
1941	9	WaccoL	5494.	0.	0.	5494.	0.	0.	0.	0.	0.	0.	7676.	0.	4295.	192100.	185623.	-6477.	-6477.
1941	10	WaccoL	1926.	0.	0.	1926.	0.	0.	0.	0.	0.	0.	7030.	-0.	-103.	185623.	180623.	-5000.	-5000.
1941	11	WaccoL	7916.	0.	0.	7916.	0.	0.	0.	0.	0.	0.	5737.	-0.	1919.	180623.	180883.	260.	260.
1941	12	WaccoL	6814.	0.	0.	6814.	0.	0.	0.	0.	0.	0.	5575.	0.	514.	180883.	181607.	725.	725.

Table 7.24
River Basin Water Budget for Example in Fundamentals Manual

River Basin Volume Budget Summary
1940-2016

	Total	Mean Annual
Naturalized flows	416455584.	5408514.0
Return flows	31112476.	404058.1
CI record constant inflows	0.	0.0
CI not exceeding 900,000 af/month	0.	0.0
Channel loss credits	8896143.	115534.3
Channel losses	1563389.	20303.8
Regulated flows at outlet	278870464.	3621694.2
Diversions	151446672.	1966839.9
Other flows at control points	16726678.	217229.6
Net evaporation	7952762.	103282.6

Inflows - Outflows	-95776.	-1243.8

Beginning reservoir storage	1949640.	25320.0
Ending reservoir storage	1852672.	24060.7

Change in storage	-96968.	-1259.3

Water balance difference	1192.	15.5
Negative inflows to control points	271551.	3526.6
Negative incremental natural flows	20693870.	268751.6
Naturalized flows at outlet	416455136.	5408508.5

Table 7.25
Monthly Volumes in the Control Point Water Budget Table

Variable	Description of Variable
1 YEAR	year
2 M	month (1, 2, 3, ... , 12)
3 CPID(cp,1)	control point identifier
<i>Monthly Volumes Used in Intermediate Computations</i>	
4 NAT(cp)	naturalized flow from <i>SIM</i> output file
5 CLC(cp)	downstream channel loss credits from <i>SIM</i> output file
6 CL(cp)	downstream channel losses from <i>SIM</i> output file
<i>Monthly Control Point Inflows in Volume Budget</i>	
7 FNAT	computed incremental naturalized flows
8 FREG	computed regulated flows entering control point
9 RET(cp)	return flows from <i>SIM</i> output file
10 CINF(cp,m)	<i>CI</i> record inflows from <i>SIM</i> input file
11 FCLC	computed upstream channel loss credits
12 FCL	computed upstream channel losses
13 FIN	total inflows to control point = FNAT+FREQ+RET(cp)+CINF(cp,m)+FCLC-FCL
<i>Monthly Control Point Outflows in Volume Budget</i>	
14 REG(cp)	regulated flows leaving control pt from <i>SIM</i> output file
15 DIV	diversion = target – shortage from <i>SIM</i> output file
16 FOTH	other releases for hydropower and instream flow = FIN – [REG(cp)+DIV+EVAP(cp)+STO(cp)–BSTO(cp)]
17 EVAP(cp)	net reservoir evaporation from <i>SIM</i> output file
<i>Reservoir Storage at Beginning and End of Month</i>	
18 BSTO(cp)	beginning-of-month storage
19 STO(cp)	end-of-month storage from <i>SIM</i> output file
<i>Water Budget</i>	
XSTO = XSUM	
20 XSTO	storage change = (19) – (18)
21 XSUM	inflows – outflows = (13) – (14) – (15) – (16) – (17)

Table 7.26
Summary Water Budget for the Entire River Basin(s)
for the Specified Period-of-Analysis

Description of Volume Quantity	Variable
Incremental naturalized flows	ΣFNAT
Return flows	$\Sigma \text{RET}(\text{cp})$
CI record constant inflows	$\Sigma \text{CINF}(\text{cp},\text{m})$
Channel loss credits	ΣFCLC
Channel losses	ΣFCL
Regulated flows leaving river basin outlet	$\Sigma \text{REG}(\text{cp})$
Water supply diversions	ΣDIV
Other releases for hydropower and instream flow	ΣFOTH
Net reservoir evaporation	$\Sigma \text{EVAP}(\text{cp})$
<hr style="width: 20%; margin: auto;"/>	
Summation of inflows minus outflows =	$\Sigma \text{FNAT} + \Sigma \text{RET}(\text{cp}) +$ $\Sigma \text{CINF}(\text{cp},\text{m}) + \Sigma \text{FCLC} - \Sigma \text{FCL} - \Sigma \text{REG}(\text{cp}) - \Sigma \text{DIV} - \Sigma \text{FOTH} - \Sigma \text{EVAP}(\text{cp})$
Beginning-of-computations reservoir storage	$\Sigma \text{BSTO}(\text{cp})$
End-of-computations reservoir storage	$\Sigma \text{STO}(\text{cp})$
<hr style="width: 20%; margin: auto;"/>	
Change in storage =	$\Sigma \text{STO}(\text{cp}) - \Sigma \text{BSTO}(\text{cp})$
Volume balance difference =	summation of inflows minus outflows – change in storage
Negative inflows to control point	ΣFINNEG
Negative incremental naturalized flows	ΣFNAT if < 0
Naturalized flows at river basin outlet(s)	$\Sigma \text{NAT}(\text{cp})$

XSTO and XSUM in Table 7.25 should have the same values. The monthly volumes included in the control point water budget table are related as follows.

$$\text{storage change} = \Sigma \text{inflows} - \Sigma \text{outflows} \quad (7.20)$$

$$\begin{aligned} \text{STO}(\text{cp}) - \text{BSTO}(\text{cp}) = & \text{FNAT} + \text{FREG} + \text{RET}(\text{cp}) + \text{CINF}(\text{cp},\text{m}) \\ & + \text{FCLC} - \text{FCL} - \text{REG}(\text{cp}) - \text{DIV}(\text{cp}) - \text{FOTH} - \text{EVAP}(\text{cp}) \end{aligned} \quad (7.21)$$

Quantities are tabulated both as total period-of-analysis volumes and mean annual volumes in the 2BUD record water budget table providing totals for the entire river basin system for the specified period-of-analysis. The sum for all months of the incremental naturalized flow volumes (FNAT) at all control points represent flows entering the river system. Regulated flow volumes (REG(cp)) at the river basin outlet or multiple outlets, as defined by *SIM CP* records, represent

river flows leaving the system. The other variables representing inflow and outflow or change in storage are also summed for all control points. The summation of all of the outflows and inflows for each month during the period-of-analysis equals the change in reservoir storage, which is the total storage at the end of the simulation less the total storage at the beginning. The variables included in the basin water budget table as listed above are related as follows.

$$\text{change in storage volume} = \Sigma \text{ inflow volume} - \Sigma \text{ outflow volume} \quad (7.22)$$

$$\begin{aligned} \Sigma \text{ inflow volume} - \Sigma \text{ outflow volume} = & \Sigma \text{FNAT} + \Sigma \text{RET}(\text{cp}) + \Sigma \text{CINF}(\text{cp},\text{m}) \\ & + \Sigma \text{FCLC} - \Sigma \text{FCL} - \Sigma \text{REG}(\text{cp}) - \Sigma \text{DIV}(\text{cp}) - \Sigma \text{FOTH} - \Sigma \text{EVAP}(\text{cp}) \end{aligned} \quad (7.23)$$

$$\text{change in storage volume} = \Sigma \text{STO}(\text{cp}) - \Sigma \text{BPSTO}(\text{cp}) \quad (7.24)$$

The volume difference in the basin budget table represents losses or gains due to computer accuracy in adding numerous numbers and thus should be very close to zero.

$$\begin{aligned} & \text{volume balance difference} = \\ & [\Sigma \text{ inflow volume} - \Sigma \text{ outflow volume}] - [\Sigma \text{STO}(\text{cp}) - \Sigma \text{BPSTO}(\text{cp})] \end{aligned} \quad (7.25)$$

The physical or computational meaning of negative inflow volumes varies with different situations. The water budget table includes the entry *negative inflows to control point*. Total inflow volumes (FIN) are determined each month for each control point. Negative values for FIN are recorded as the variable FINNEG. The summation of FINNEG for all control points and all months are included in the river basin volume budget table. Options for dealing with negative control point total inflows are selected by 2BUD record field 7.

Incremental naturalized flows (FNAT) are negative if the flows at upstream control points exceed the flow at the control point in question. The summation of negative incremental volumes is included in the basin budget table for general information. The negative incremental naturalized flows generated by the *TABLES 2BUD* routine may be different than the negative incremental flow adjustments in *SIM*. Whereas *SIM* looks at all control points located optionally either downstream or upstream in computing negative incremental naturalized flow adjustments, the *TABLES 2BUD* routine considers only the upstream control point(s) located immediately adjacent to the control point being considered.

With the default blank 2BUD field 9 for parameter BASIN, the last variable listed in the river basin water budget table is naturalized flows at the one or more outlets. Outlets are defined by *SIM CP* records. The total naturalized flows NAT(cp) at outlets should be the same as the sum of the incremental flows ΣFNAT , which is the first entry in the table.

Other Reservoir Releases or Other Flows

The other flow volume (FOTH) in Eq. 7.23 and Tables 7.25 and 7.26 is computed as follows.

$$\text{FIN2} = \text{flow in} = \text{flow out} + \text{storage change} \quad (7.26)$$

$$\text{FIN2} = \text{REG}(\text{cp}) + \text{DIV} + \text{EVAP}(\text{cp}) + \text{STO}(\text{cp}) - \text{BSTO}(\text{cp}) \quad (7.27)$$

$$\text{FOTH} = \text{FIN2} - \text{FIN} \quad (7.28)$$

The other flow volume FOTH is by definition the additional flow component required to make the volume budget at a control point perfectly balance.

The FOTH term models releases made specifically for hydroelectric power generation or releases from storage for meeting instream flow requirements. Passing of reservoir inflows for downstream instream flow requirements and water supply releases that incidentally generate hydropower are not included in this category of other releases. The return flows in the *SIM* output file control point records include reservoir releases to meet hydropower and instream flow requirements. Return flows incorporating these other reservoir releases are included the regulated flows and control point inflows. To maintain the volume balance, hydropower and instream flow releases must also be included in the computations in the same way as diversions as quantities in the control point outflows. *SIM* negative incremental naturalized flows and options for dealing with them (*JD* record field 8) may also prevent the control point volume budget from balancing without the FOTH term.

Control Point Sequencing for the 2BUD Record Water Budget

SIM is executed with output records for all control points written to the OUT file. Water right and reservoir output records are not needed. Within each month of the 2BUD computational algorithm, the water budget computations are performed by control point in upstream-to-downstream sequence. A control point is considered only after 2BUD computations are completed for all control point located upstream. Regulated flows from upstream control points adjusted for channel losses are a component of the inflows to the control point in question.

A 1CPT record may be placed before the 2BUD record to create an ICP(I) array stored in computer memory that defines the upstream-to-downstream ordering of control points. The default 1CPT record field 3 option 1 is selected. If the control points are already in upstream-to-downstream order in the *SIM* DAT file, the 1CPT record is not needed. Alternatively, the 1CPT record may be used to permanently rearrange the sequencing of *CP* records in a *SIM* DAT file.

A control point other than the default basin outlet may be entered in 2BUD record field 2. The river basin water budget is valid for a control point specified in field 9 only if all control points listed prior to that control point in the sequencing are located upstream, which may not necessarily be the case if the control point sequencing is performed for the entire system above the basin outlet(s). An individual control point budget for any specified control point is always fine even if the sequencing is performed considering all control points above the basin outlet(s).

CHAPTER 8

SHORT-TERM CONDITIONAL RELIABILITY MODELING

Conditional reliability modeling (CRM) consists of developing short-term reliability and frequency estimates conditioned on preceding reservoir storage. The terms *conditional* and *short-term* are used interchangeably. CRM is based on dividing a long hydrologic period-of-analysis into many shorter simulation sequences. The simulation is repeated for each hydrologic sequence with the same initial storage condition. Water supply and hydropower reliability indices and flow and storage frequency relationships are developed from the simulation results. The programs *SIM* or *SIMD* perform the multiple short-term simulations with the specified starting reservoir storage contents. Routines in the program *TABLES* read the simulation results and perform reliability and frequency analyses.

A separate initial CRM version of *WRAP* [42] was subsequently redesigned with the newer computational methods described in this chapter integrated directly into the generic *SIM* and *TABLES*. The current CRM methodologies are illustrated with a case study application presented in other publications [37, 38] as well as the examples presented in this chapter.

Conventional Versus Conditional Reliability Modeling

WRAP was originally designed for long-term planning studies and preparation and evaluation of water right permit applications. Conditional reliability modeling (CRM) features expand *WRAP* capabilities to support short-term drought management and operational planning activities in which consideration of preceding reservoir storage levels is important. Using CRM, the likelihood of meeting reservoir storage, water supply diversion, instream flow, and hydroelectric power generation targets during the next month, next several months, next year, or next several years is assessed as a function of the amount of water currently in storage along with all the other information otherwise reflected in *WRAP*. Water supply reliabilities and storage and flow frequencies are conditioned on preceding storage contents.

A *WRAP* simulation study, either conventional or CRM, involves assessing capabilities for meeting specified water management and use requirements, with river basin hydrology being represented by historical naturalized stream flow sequences and net reservoir evaporation less precipitation rates. For example, based on the availability of historical flow records, a 1940-2013 period-of-analysis may be adopted to represent the hydrologic characteristics of a river basin. In a conventional *WRAP* simulation, the model allocates water to meet specified water management/use requirements during each sequential month of a single 888-month hydrologic sequence starting in January 1940. Initial reservoir storage contents are specified corresponding to the beginning of January 1940 in the hydrologic period-of-analysis. In CRM, the long sequences of naturalized flows and net evaporation rates are divided into many short sequences. For example, the 1940-2013 hydrologic period-of-analysis may be divided into 74 annual simulation sequences starting and ending in specified months. The system is simulated 74 times with 74 different naturalized stream flow and net evaporation sequences, with each simulation sequence having the same starting reservoir storage contents. The reliability indices and frequency relationships developed from the CRM simulation results have the same format as with the conventional *WRAP* modeling approach but are interpreted differently.

With the conventional WRAP modeling approach, reliability parameters provide a measure of the likelihood of meeting water supply, environmental instream flow, and hydroelectric power production requirements during any randomly selected future month or year without regard to the amount of water actually contained in reservoir storage today. This type of modeling is designed for long-term planning studies and preparation and evaluation of water right permit applications. The purpose of the CRM features is to expand WRAP capabilities to include evaluation of reliabilities in meeting water needs during the next relatively short periods of time ranging from a month to a year or perhaps several years, which is highly dependent on the amount of water currently in storage. Reliabilities and frequencies are conditioned upon preceding storage. The likelihood of a reservoir being full or almost full three months from now is significantly higher if the reservoir is almost full now than if it is almost empty now.

CRM is a decision-support tool for water management during drought, developing river/reservoir system operating policies, administration of water right systems and water supply contracts, and related applications. CRM may be applied by a regulatory agency in deciding upon water use curtailment actions during drought. Reservoir management agencies may use the model to develop permanent operating rules or to develop operating plans for the next year or season in ongoing operational planning activities. Commitments to water users may be set annually or seasonally depending on the amount of water in storage at the beginning of the season or year. For proposed reservoir construction projects, CRM may be used to evaluate impacts on the other water users in the river basin during the initial impoundment period.

Computer Programs, Data Files, and Input Records

Conditional reliability modeling capabilities are included in *SIM*, *SIMD*, and *TABLES*. The multiple short-term simulations are performed within either *SIM* or *SIMD*. The *SIMD* version provides the option of performing the simulation computations using a daily time interval and then aggregating the daily results to monthly totals. Otherwise, a CRM analysis is performed in the same manner with either *SIM* or *SIMD*. *TABLES* reads the monthly simulation results from a *SIM* or *SIMD* output file and creates reliability and frequency tables.

SIM or *SIMD* is switched to the CRM mode by entering a conditional reliability *CR* record in the input file. The *CR* record is the only *SIM/SIMD* input record that is used solely for CRM. The *CR* record sets the time parameters that control the subdivision of the hydrologic period-of-analysis into multiple short-term sequences. Without a *CR* record, the model performs a conventional single hydrologic period-of-analysis simulation. Simulation results are stored in the main *SIM/SIMD* output file with filename extension *OUT* or *CRM* which is read by *TABLES*. Either CRM or non-CRM simulation results can also be written to *SOU* and/or *DSS* files.

Instructions for preparing CRM-related input records for *TABLES* are provided in the *Users Manual*. *TABLES* provides alternative approaches for assigning probabilities to each of the CRM hydrologic sequences. With the default equal-weight option, the *TABLES* input records are the same as with a conventional non-CRM analysis, with the exception of adding a *5CRM* record. The *5CRM* record, which has no actual input data, is used to switch *TABLES* from the conventional to CRM mode of analysis. A set of optional *5CR1* and *5CR2* records activates options that assign probabilities to each hydrologic sequence, which may vary between sequences, based on either a storage-flow-frequency (SFF) or flow-frequency (FF) relationship. The correlation coefficient

5COR record provides auxiliary capabilities for investigating the correlation between naturalized flow volume and preceding reservoir storage content.

The results of *SIM/SIMD* conventional long-term and CRM short-term simulations are recorded in OUT and CRM files, respectively. The OUT and CRM output files contain the same type of simulation results data in the same format. However, the CRM file created by *SIM* or *SIMD* reflects repetition of the same user-specified initial storage conditions at the beginning of each of the multiple user-defined hydrologic sequences. Simulation results can also be recorded directly in a simulation output SOU or data storage system DSS file without use of *TABLES*.

The *TABLES 5CR1* record optional creation of a storage-flow-frequency (SFF) array uses an OUT output file from a conventional long-term *SIM/SIMD* simulation. The *5CR2* record uses a CRM output file from a CRM application of *SIM* or *SIMD*. Thus, output files from two separate executions of *SIM/SIMD* may be read by *TABLES* in performing CRM computations activated by *5CR1* and *5CR2* record options. The *5CR1* and *5CR2* records contain options that allow creation of an extra file, with filename extension SFF, for a storage-flow-frequency (SFF) array. However, the SFF array may also be developed and applied without reading and writing to a SFF file. Options also allow a beginning-of-simulation storage file, with filename extension BRS, to be written by *SIM/SIMD* and read by *TABLES*.

All of the various tables and data listings created by *TABLES* are applicable to either CRM or conventional simulations. The format of the tables and data listings are essentially the same for either CRM or conventional simulations. The primary difference in appearance is that whereas a conventional simulation is organized based on 12-month years, CRM simulation results are organized by sequences with lengths in months specified by the *SIM CR* record. Some tables provide additional information in the headings for CRM applications regarding the *CR* record parameters that define the organization of the hydrologic simulation sequences.

Reiterating, the difference between a conventional *WRAP* simulation and a CRM application is:

- A conventional simulation is based on sequential computations for the entire hydrologic period-of-analysis as a single simulation.
- In a CRM execution of *SIM* or *SIMD*, the hydrologic period-of-analysis is divided into many shorter simulation periods with the storage contents of each reservoir being reset to pre-specified initial levels at the beginning of each simulation period.

SIM/SIMD input files are the same for either a conventional or CRM simulation, except a conditional reliability *CR* record is added for a CRM simulation. The output filenames have the extensions OUT and CRM, respectively. The content and format of *SIM* output records are defined in Tables 5.2, 5.3, 5.4, and 5.5 of this *Reference Manual*. The first two parameters from the *CR* record are added to the 5th record of the *SIM* output file. The content and format of the individual water right, control point, and reservoir/hydropower output records are identical for CRM versus conventional simulations. The only difference in the output file format is the monthly sequencing of the records. All output is written within a monthly computational loop. As discussed below, the CRM annual option may exclude certain months of the year, and the monthly option may exclude a few months and may repeat years and months multiple times.

Multiple Short-Term Simulations with the Same Initial Storage

The variables entered on the *CR* record are shown in Table 8.1, which is also included in the *Users Manual*. Entering a *CR* record in the DAT input file switches *SIM* or *SIMD* from the default conventional simulation mode to the conditional reliability modeling (CRM) mode.

Table 8.1
Conditional Reliability *CR* Record
(Reproduced from *Users Manual*)

field	columns	variable	format	value	Description
1	1-2	CD	A2	CR	Record identifier.
2	3-8	CR1	I6	+ blank,0	Length of simulation period in months. Default = 12 months
3	9-16	CR2	I8	+ blank,0,-	Starting month (1, 2, .., 12) for annual cycle option. Monthly cycle option is activated.
4	17-24	CR3	I8	blank,0 + -1	CRM file is limited to last 12 months of sequence. CRM file includes 12 months starting with CR3. All months are included in CRM file. CR3 is applicable only if CR1 > 12 months.
5	25-32	CR4	F8.0	+ blank,0 ≤ -1.0	Factor by which all starting storages are multiplied. Default = 1.0 Storage multiplier factor = 0.0
6	33-40	CR5	I8	blank,0,1 2	Cyclic repetition of months if CR1>12 and CR2>0. No repetition or cycling of months of hydrology.

The following parameters are specified on the *CR* record. CR1 has a default of 12 months if field 2 is left blank. The other *CR* record parameters are optional. CR3 and CR5 are applicable only if CR2 is not blank or zero.

- CR1 is the length of the simulation period. Each hydrologic sequence is CR1 months long.
- CR2 activates the annual cycle option and is the starting month of each sequence. Unlike the monthly cycle option, the annual cycle starts all simulation sequences in the same month.
- CR3 is relevant only if the sequence length CR1 is greater than 12 months. With CR1 greater than 12 months, the default option is to record the simulation results for only the last 12 months in the *SIM* CRM output file for each simulation sequence. A positive CR3 results in recording the simulation results for the 12 months of each sequence from month CR3 to month CR3+11. A CR3 of -1 results in all months being included in the CRM file.
- CR4 is a factor by which all beginning reservoir storage volumes are multiplied (default=1.0).
- CR5 is relevant only if CR1 is greater than 12 months and the annual cycle option is adopted (CR2 is not zero). With the default CR5, repetitive cycling is performed allowing individual months of hydrology input from the FLO, EVA, and FAD files to be included in multiple simulation sequences. With CR5 option 2, the hydrology files are read without

cycling and thus each month of data is included in only one of the simulation sequences. Hydrology is employed exactly as read from the FLO, EVA, and FAD files.

Specifying Simulation Sequences

The overall period of time for which stream inflows and evaporation-precipitation depths are included in the *SIM* FLO and EVA files is divided into multiple CRM simulation periods. The following two alternative approaches are provided for organizing the simulation periods.

1. The *annual cycle option* is defined as starting each simulation sequence in the same specified month ($CR2 = 1, 2, 3, \dots, 12$) of the year. The annual cycle option is activated by a non-zero $CR2$ in *CR* record field 3. $CR1$ may be any length.
2. The *monthly cycle option* is automatically activated if $CR2$ is zero (blank field 3). With the monthly cycle option, the multiple simulations with the same starting storage condition begin in different months with approximately the same number of simulations beginning in each of the 12 months of the year.

With either option, the hydrologic simulation sequence length may be any nonzero integer number of months. The annual cycle option captures seasonality. All of the simulations start in the same month of the year and represent the same seasons. However, the number of simulations is limited to the number of years in the total period-of-analysis or less. The monthly cycle option allows up to 12 times more simulations than the annual cycle option. With the monthly cycle option, the number of simulations is limited to the number of months indicated by Equation 8.1 presented later. The accuracy of frequency and reliability estimates depends both on properly modeling seasonal characteristics of hydrology and maximizing the number of hydrologic sequences used in the analyses. The choice of which option to adopt for a particular application depends upon the relative importance of these two considerations.

The message MSS file displays trace messages during a *SIM/SIMD* execution which are partially controlled by the variable *ICHECK* on the *JD* record. An *ICHECK* of 10 activates a trace written to the MSS file that shows the sequencing of years and months in the conditional reliability simulations. The trace is written within the computational loops and lists all months, shows the subdivision of months into simulation sequences, and indicates which months are excluded from the simulation results.

Annual Cycle Option

The *annual cycle option* is defined by a starting month ($CR2$) ranging from 1 to 12 and a simulation period ($CR1$) ranging from 1 to any integer number of months which may be less than or greater than 12 or may be 12. Consider a *SIM* input dataset with a 1940-2013 hydrologic period-of-analysis which contains 74 years (888 months). The CRM sequences could be organized with a starting month of May ($CR2 = 5$) and simulation period of three months ($CR1 = 3$). Seventy-four simulation sequences would be defined as follows.

Sequence 1: May 1940 through July 1940
Sequence 2: May 1941 through July 1941
Sequence 3: May 1942 through July 1942

Sequence 73: May 2012 through July 2012
Sequence 74: May 2013 through July 2013

Results are written to the output file for all of the months included in the simulation sequences. For the preceding example, the *WRAP-SIM* output file with filename extension CRM will contain results for May, June, and July for each of the 74 years.

As another example, assume that the starting month is set at May ($CR2 = 5$) and the simulation period ($CR1$) is the default of 12 months. The 74-year 1940-2013 overall hydrologic period-of-analysis is divided into the following 73 annual sequences. The 12 months January 1940 through April 1940 and May 2013 through December 2013 are not used. Seventy-three simulations are performed with the following hydrologic periods-of-analysis with each simulation starting with the same beginning-of-May reservoir storage contents.

Sequence 1: May 1940 through April 1941
Sequence 2: May 1941 through April 1942
Sequence 73: May 2012 through April 2013

$CR1$ may exceed 12 months. Assume that the starting month is set at May ($CR2 = 5$) and the simulation period ($CR1$) is 30 months. The 1940-2013 hydrologic period-of-analysis is divided into the following 72 annual sequences which are tabulated in Table 8.2. The six months January 1940 through April 1940 and November 2013 through December 2013 are not used.

Cycle 1

Sequence 1: May 1940 through October 1942
Sequence 2: May 1943 through October 1945
Sequence 3: May 1946 through October 1948
Sequence 22: May 2003 through October 2005
Sequence 23: May 2006 through October 2008
Sequence 24: May 2009 through October 2011

Cycle 2

Sequence 25: May 1941 through October 1943
Sequence 26: May 1944 through October 1946
Sequence 27: May 1947 through October 1949
Sequence 46: May 2004 through October 2006
Sequence 47: May 2007 through October 2009
Sequence 48: May 2010 through October 2012

Cycle 3

Sequence 49: May 1942 through October 1944
Sequence 50: May 1945 through October 1947
Sequence 51: May 1948 through October 1950

...
 Sequence 70: May 2005 through October 2007
 Sequence 71: May 2008 through October 2010
 Sequence 72: May 2011 through October 2013

Table 8.2
WRAP-SIM Conditional Reliability Modeling (CRM) Simulation Sequences for
 Sequence Length CR1 of 30 Months, Starting Month CR2 of 5 (May), and Default CR5

Cycle 1			Cycle 2			Cycle 3		
1	May 40	Oct 42	25	May 41	Oct 43	49	May 42	Oct 44
2	May 43	Oct 45	26	May 44	Oct 46	50	May 45	Oct 47
3	May 46	Oct 48	27	May 47	Oct 49	51	May 48	Oct 50
4	May 49	Oct 51	28	May 50	Oct 52	52	May 51	Oct 53
5	May 52	Oct 54	29	May 53	Oct 55	53	May 54	Oct 56
6	May 55	Oct 57	30	May 56	Oct 58	54	May 57	Oct 59
7	May 58	Oct 60	31	May 59	Oct 61	55	May 60	Oct 62
8	May 61	Oct 63	32	May 62	Oct 64	56	May 63	Oct 65
9	May 64	Oct 66	33	May 65	Oct 67	57	May 66	Oct 68
10	May 67	Oct 69	34	May 68	Oct 70	58	May 69	Oct 71
11	May 70	Oct 72	35	May 71	Oct 73	59	May 72	Oct 74
12	May 73	Oct 75	36	May 74	Oct 76	60	May 75	Oct 77
13	May 76	Oct 78	37	May 77	Oct 79	61	May 78	Oct 80
14	May 79	Oct 81	38	May 80	Oct 82	62	May 81	Oct 83
15	May 82	Oct 84	39	May 83	Oct 85	63	May 84	Oct 86
16	May 85	Oct 87	40	May 86	Oct 88	64	May 87	Oct 89
17	May 88	Oct 90	41	May 89	Oct 91	65	May 90	Oct 92
18	May 91	Oct 93	42	May 92	Oct 94	66	May 93	Oct 95
19	May 94	Oct 96	43	May 95	Oct 97	67	May 96	Oct 98
20	May 97	Oct 99	44	May 98	Oct 00	68	May 99	Oct 01
21	May 00	Oct 02	45	May 01	Oct 03	69	May 02	Oct 04
22	May 03	Oct 05	46	May 04	Oct 06	70	May 05	Oct 07
23	May 06	Oct 08	47	May 07	Oct 09	71	May 08	Oct 10
24	May 09	Oct 11	48	May 10	Oct 12	72	May 11	Oct 13

With the annual cycle option, if the sum of CR1 and CR2 is 13 or less, the number of sequences equals the number of years reflected in the hydrology dataset (*IN* and *EV* records). If CR1 is 12 or less and the sum of CR1 and CR2 exceeds 13, the number of sequences used in the CRM analysis is one less than the number of years of hydrology. If CR1 exceeds 12 months, the number of sequences will be less than the number of years and may be less by more than one.

Annual Cycle Approach CR3 and CR5 Options

The parameters CR3 and CR5 entered in *CR* record fields 4 and 6 apply only to the annual cycle option. CR3 and CR5 are relevant only if CR2 is non-zero meaning a starting month is

specified. CR3 and CR5 are relevant only if CR1 is greater than 12 months. The sequence length CR1 may range from one to 12 times the number of years of hydrology data (*IN* and *EV* records). CR3 controls the number of months that are recorded in the simulation results output file. CR5 controls whether years of hydrology are repeated in the cycling to increase the number of hydrologic sequences.

CR3 does not affect the *SIM* simulation computations but rather controls which months of simulation results are recorded in the *SIM* output CRM, SOU, and DSS files. The default (CR3 = 0) consists of recording the simulation results for only the last 12 months for each simulation sequence. With a -1 entered for CR3 in CR record field 4, the simulation results for all months are included in the *SIM* output files. With a positive integer specified for CR3, the simulation results for 12 months beginning with month CR3 of each sequence are recorded in the *SIM* output. For the 72 thirty-month long sequences listed in Table 8.2, either a 19 or 0 entered in field 3 of the CR3 record or a blank field 3 results in the last 12 months (months 19 through 30) of each simulation sequence being included in the CRM, SOU, and DSS files. This consists of inclusion of the last November through October of each simulation sequence in the output files.

The choice of *SIM* CR3 option depends upon options to be employed in *TABLES* to create frequency and reliability tables. *TABLES* 2FRE, 2FRQ, 2REL, and 2RES records include options for specifying a specific month for which tables are to be created. For example, based on the results of the *SIM* simulation illustrated in Table 8.2, a *TABLES* 2FRE record storage-frequency table may be developed for reservoir storage contents at the end of August, twenty-eight months after starting with a specified beginning-of-May storage. Each of the seventy-two 30-month simulation sequences include three Augusts but only the last August of each sequence is relevant to the frequency analysis. Thus, the default CR3 option (CR3 = 0) is employed.

Another analysis might entail a 2REL water supply diversion reliability table with reliabilities defined based on meeting diversion targets during the entire 30-month simulation period. Although the CRM starting storage content is specified for the beginning-of-May, the diversion reliabilities are not for a specific month of the year. Thus, -1 is entered for CR3.

CR5 option 2 results in each month of hydrology being incorporated in only one of the simulation sequences. With CR5 record option 2 activated in CR record field 6, only the first 24 sequences of Table 8.2 are adopted, thus reducing the 72 sequences to the 24 listed in Table 8.3.

Table 8.3
CRM Sequences for CR1 of 30 Months, CR2 of 5 (May), and CR5 Option 2

1	May 40	Oct 42	9	May 64	Oct 66	17	May 88	Oct 90
2	May 43	Oct 45	10	May 67	Oct 69	18	May 91	Oct 93
3	May 46	Oct 48	11	May 70	Oct 72	19	May 94	Oct 96
4	May 49	Oct 51	12	May 73	Oct 75	20	May 97	Oct 99
5	May 52	Oct 54	13	May 76	Oct 78	21	May 00	Oct 02
6	May 55	Oct 57	14	May 79	Oct 81	22	May 03	Oct 05
7	May 58	Oct 60	15	May 82	Oct 84	23	May 06	Oct 08
8	May 61	Oct 63	16	May 85	Oct 87	24	May 09	Oct 11

Monthly or Non-Annual Cycle Option

The *monthly (non-annual) cycle option* is the other alternative for organizing CRM simulation sequences. This approach allows creation of a greater number of sequences by removing the restriction that all sequences start in the same specified month. With the monthly cycle option, the first sequence begins in the first month of the first year and has the length specified by CR1. The second sequence begins in the next month following completion of the first sequence. The sequencing recycles after reaching the end of the last year. Each cycle begins one month after the preceding cycle. The number of complete sequences is:

$$\text{number of sequences} = (12)(\text{number of years}) - \text{CR1} + 1 \quad (8.1)$$

Applying the monthly cycle option to the 1940-2013 example, for a CR1 of 4 months, 885 sequences will be created as follows with the computations performed and the simulation results output in the following order.

Cycle 1

Sequence 1: January 1940 through April 1940
Sequence 2: May 1940 through August 1940
Sequence 3: September 1940 through December 1940
Sequence 4: January 1941 through April 1941
...
Sequence 221: May 2013 through August 2013
Sequence 222: September 2013 through December 2013

Cycle 2

Sequence 223: February 1940 through May 1940
Sequence 224: June 1940 through September 1940
...
Sequence 442: February 2013 through May 2013
Sequence 443: June 2013 through September 2013
Three months not used: October–December 2013

Cycle 3

Sequence 445: March 1940 through June 1940
Sequence 446: July 1940 through October 1940
...
Sequence 663: March 2013 through June 2013
Sequence 664: July 2013 through October 2013
Two months not used: November–December 2013

Cycle 4

Sequence 665: April 1940 through July 1940
Sequence 666: August 1940 through November 1940
...
Sequence 884: April 2013 through July 2013
Sequence 885: August 2000 through November 2013
One month not used: December 2013

Specifying Initial Storage Contents of Each Reservoir

In conditional reliability modeling, the same initial reservoir storage contents are reset at the beginning of each of the simulations. *SIM/SIMD* options for specifying initial storages do not differentiate between a conventional and CRM simulation other than the factor CR4 entered on the *CR* record. Initial storage content may be entered in *WS* record field 8 for individual reservoirs. Initial storages may be entered as a beginning-ending-storage BES file (*JO* record field 5) for any or all reservoirs. Initial storage content is automatically set equal to the storage capacity by default for any reservoir for which an initial storage is not otherwise specified.

CR4 entered on the *CR* record is a factor by which the initial storage of all reservoirs is multiplied. For example, to set the initial storage in all reservoirs at 75 percent of capacity, a value of 0.75 may be entered on the *CR* record for CR4 with initial storages not otherwise specified and thus defaulting to capacity. With 0.75 entered for CR4, each simulation sequence begins with the storage level of each reservoir at 75 percent of the beginning-of-simulation storage contents otherwise specified.

TABLES Equal-Weight versus Probability Array Strategies

Two alternative strategies, called the *equal-weight option* and *probability array option*, are provided for *TABLES* to associate probabilities with each of the multiple simulation sequences generated by *SIM* or *SIMD*. With the *equal-weight option*, the reliability and frequency computations activated by *2REL*, *2FRE*, *2FRQ*, and *2RES* records are the same for either a CRM analysis or conventional long-term simulation. Each simulation sequence is weighted equally or counted once in applying the basic equations (Eqs. 8.2–8.7) covered in the following discussion. The alternative *probability array option* activated by the *5CR1* and *5CR2* records covered in the latter half of this chapter is based primarily on developing an array assigning probabilities to the multiple simulation sequences as a function of preceding storage contents or change in preceding storage contents but also includes other optional features.

The default equal-weight approach is simple and generally valid. It is covered first in the following presentation and then illustrated with three examples. Most of the complexity of this chapter is associated with the optional probability array option methods for enhancing probability estimates associated with the individual simulations, which are presented later after the examples applying the equal-weight option.

Reliabilities associated with meeting water supply diversion, hydroelectric power generation, and environmental instream flow targets over the next several months and the amount of water contained in storage at the end of the next several months depend on both the:

1. amount of water currently available in reservoir storage
2. hydrology that occurs over the future several-month period of interest as represented by naturalized flows and net reservoir evaporation rates

Beginning reservoir storage and naturalized stream flow represent the two sources of available water. The relative importance of these two sources in determining water supply reliabilities and end-of-period reservoir storage frequencies depends upon their relative magnitude. Beginning reservoir storage is specified by the model-user as input to the *SIM* simulation. The conditional

reliability modeling (CRM) options outlined in the latter half of this chapter focus on the hydrology, particularly on relating the probabilistic characteristics of the multiple sequences of naturalized stream flows to specified known beginning storage conditions.

The relative importance of beginning storage versus hydrology over the time period of interest is a key consideration governing the choice between the *equal-weight* and *probability array* options. The other key factor is the degree of correlation between naturalized flow over the period of interest and the known preceding change in storage contents. The last section of the chapter is a comparative summary of the alternative methodologies.

Program TABLES Reliability and Frequency Tables

The program *TABLES* performs reliability and frequency analyses using the simulation results read from a *SIM* or *SIMD* output CRM file. *TABLES* also contains routines that simply reorganize and tabulate the simulation results as user-specified tables. The *TABLES* routines applied in conventional applications are also applicable to CRM. The tables created for conventional non-CRM applications have the same format and content when used with CRM. However, frequency and reliability indices are interpreted differently for different types of applications. The CRM frequency and reliability estimates always reflect user-specified preceding reservoir storage contents and multiple hydrologic simulation sequences.

The *2REL* record creates reliability tables for diversion or hydropower targets for water rights, water right groups, control points, or reservoirs. The *2FRE* and *2FRQ* records create frequency tables for naturalized flow, regulated flow, unappropriated flow, reservoir storage volume, reservoir surface elevation, and instream flow shortage. The *2RES* record creates reservoir draw-down frequency and storage reliability tables. The tables may be developed from the results of either a conventional simulation or CRM simulation with any of the CRM options.

TABLES reliability and frequency tables are based on the concepts expressed by Equations 8.2–8.7 and described in this chapter. With a dataset for a conventional WRAP simulation available, the switch from conventional long-term modeling to short-term conditional reliability modeling can be simple with little additional input required or significantly more complex depending upon the CRM options adopted. The probability array options are more complicated than the equal-weight approach.

Reliability and frequency indices may consider all months or alternatively may be for a specified month. For example, a frequency table may be created for regulated flows at specified control points during August or end-of-month storage contents for August. Likewise, a reliability table may be constructed for meeting water supply diversion targets in any randomly selected future month or alternatively may be defined for a particular month such as August.

Reliability Analyses of Water Supply Diversions and Hydropower Generation

Period reliability is based on counting the number of periods of the simulation during which the specified demand target is either fully supplied or a specified percentage of the target is equaled or exceeded. A *TABLES* reliability summary includes tabulations of period reliabilities expressed both as the percentage of months and the percentage of years (or CRM sequences) during the

simulation during which either water supply diversions or hydroelectric energy produced equaled or exceeded specified magnitudes expressed as a percentage of the target demand. The various variations of period reliability (R_p) are computed by *TABLES* from the results of a *SIM/SIMD* simulation as:

$$R_p = \frac{n}{N} (100\%) \quad (8.2)$$

where n denotes the number of periods during the simulation for which the specified percentage of the demand is met, and N is the total number of periods considered.

Volume reliability is the percentage of the total demand that is actually supplied. For water supply diversions, the demand is a volume. For hydropower, the demand is energy generated. Volume reliability (R_v) is the ratio of the total diversion volume supplied or energy produced (v) to the total volume or energy target demanded (V) during a specified period of time.

$$R_v = \frac{v}{V} (100\%) \quad (8.3)$$

Equivalently, R_v may be viewed as the ratio of the mean actual water supply diversion rate to mean target diversion rate or the ratio of the mean energy production rate to mean target rate.

In either a conventional or CRM application, *TABLES* applies Eqs. 8.2 and 8.3 using data from the simulation results output file, with filename extension CRM, created by *SIM* or *SIMD*. For a conventional simulation, the reliability indices are expressions for capabilities for meeting water supply, hydropower, instream flow, and reservoir storage requirements in the long-term without consideration of the amount of water in storage today. In a CRM application, the reliabilities reflect capabilities for meeting these requirements during the next several months or in a particular month in the near future given known preceding reservoir storage levels. Short-term CRM reliabilities are conditioned on known initial reservoir storage contents.

Frequency Analyses of Stream Flow and Reservoir Storage

In general, exceedance frequency, expressed as a percentage ranging from 0 to 100%, or exceedance probability, expressed as a fraction between 0 and 1.0, represents the estimated likelihood of equaling or exceeding particular values of a random variable. Exceedance frequency is an expression of the percentage of time that particular flow or storage amounts can be expected to occur or equivalently the probability of a certain amount of water being available. *TABLES* provides options to model the probabilistic nature of naturalized flows, regulated flows, unappropriated flows, instream flow shortages, reservoir storage volume, and reservoir water surface elevation in terms of relative frequency (Equation 8.4) or alternatively using the normal or log-normal probability distribution functions (Eqs. 8.6 and 8.7).

From a relative frequency perspective, exceedance frequency (F) and exceedance probability (P) are expressed as:

$$F = \frac{n}{N} (100\%) \quad (8.4)$$

$$P = \frac{n}{N} \quad (8.5)$$

where n is the number of time periods that a specified amount is equaled or exceeded and N is the total number of time periods considered. Exceedance frequency is computed in the *TABLES 2FRE*, *2FRQ*, and *2RES* record routines based on Equation 8.4 with n being the number of months during the *SIM* simulation that a particular flow or storage amount is equaled or exceeded. N is the total number of months considered.

Alternatively, the *TABLES 2FRE* record provides options to apply the normal or log-normal probability distributions to the series of monthly flow and storage volumes generated by *SIM*. The random variable X in Eq. 8.6 may be naturalized flows, regulated flows, unappropriated flows, instream flow shortages, or reservoir storage volumes or elevations.

$$X = \bar{X} + z S \quad (8.6)$$

The frequency factor (z) is derived from a normal probability table, and \bar{X} and S denote the sample mean and standard deviation of the data read from the *SIM* output file.

The log-normal distribution consists of the normal distribution applied to the logarithms of X , with Eq. 8.6 expressed as Eq. 8.7 with z still derived from the normal distribution.

$$\log X = \overline{\log X} + z S_{\log X} \quad (8.7)$$

In the probability distribution options activated by the *2FRE* record, exceedance probabilities are assigned to the random variable X by fitting the normal or log-normal distribution in a standard manner outlined in statistics textbooks. The mean $\overline{\log X}$ and standard deviation $S_{\log X}$ of the logarithms of the data from the *SIM* output file are computed. The frequency factor z for specified exceedance probabilities from a normal probability table are built into *TABLES*.

CRM frequency analyses are typically performed with *TABLES* for a particular month using *SIM* simulation results reflecting the annual cycle hydrologic sequencing option. For example, a *2FRE* reservoir storage-frequency table may be developed for the storage content at the end-of-October conditioned upon a specified storage content at the beginning-of-May. The storage-frequency relationship developed with *TABLES* refers specifically to storage at the end of October computed by *SIM* based upon a given storage content occurring six months earlier. The *SIM* annual cycle option is required for this analysis. The monthly cycle option is not valid for applications that specify specific months of the year. With the annual cycle option with a sequence length exceeding 12 months, the same month can occur multiple times in each sequence, but only one of the concurrences of that month is adopted in the frequency computations. *TABLES* includes warning and error messages designed to prevent inappropriate use of the options specifying a month in CRM analyses. However, the user must also apply caution in this regard in meaningfully applying the analysis capabilities of *SIM* and *TABLES*.

Program TABLES Input Records and Resulting Tables

The default equal-weight CRM option consists of performing the reliability and frequency computations activated by *2REL*, *2FRE*, *2FRQ*, and *2RES* records identically the same for a CRM

analysis as with a conventional long-term simulation. The format and content of the *SIM/SIMD* output file records are the same with either a conventional or CRM simulation. Program *TABLES* reads the *SIM/SIMD* simulation results and processes the data through reliability and frequency algorithms that are not affected by whether the data was generated by a single conventional long-term simulation or multiple equally-weighted CRM simulations. Of course, resetting initial storage contents does significantly affect the numerical values reflected in the *SIM/SIMD* simulation results and corresponding *TABLES* frequency and reliability analyses results. Information from the *CR* record is included in the table headings.

Although the content and format of the *SIM/SIMD* output file records are the same for either CRM or conventional non-CRM applications, the total number of output records varies with variations in the number of years and months. For a conventional simulation, there are 12 months in each year. With the CRM annual cycle option with sequence length $CR1 \leq 12$, there are $CR1$ months for each year, but the number of sequences is either the number of years or one less. With the CRM monthly cycle option, there are also $CR1$ months for each sequence, but the number of sequences given by Equation 8.1 approaches the total number of months in the overall period-of-analysis. In all cases, the *TABLES* routines cycle through *SIM* simulation results organized by groups of months contained within years. For each month, the output records are organized by user-specified groups of control points, water rights, and reservoirs.

Reliability indices are developed by *TABLES* as specified by a *2REL* record. Frequency tables are created with a *2FRE* or *2FRQ* record. Storage reliabilities and draw-down frequencies are determined with a *2RES* record. Reliabilities are computed for either water supply diversion or hydroelectric energy targets for individual water rights, the aggregation of all rights associated with individual control points or reservoirs, groups of selected rights, or the aggregation of all rights in the model. *2FRE* and *2FRQ* frequency tables may be developed for

- naturalized flow, regulated flow, unappropriated flow, and reservoir storage volume for specified control points
- instream flow shortages and reservoir storage volume for specified water rights
- reservoir storage volume and water surface elevation for specified reservoirs

Reliability and frequency analyses may be performed for a specified individual month of the year or for the aggregation of all the months included in the simulation. All 12 months of the year are included in a conventional *SIM* simulation. For a CRM analysis, the months for which reliabilities and frequencies may be computed are those included in the *SIM* simulation sequences as defined by the *CR* record. The annual portion of a reliability table refers to the aggregation of 12 months for a conventional simulation and the number of months entered for $CR1$ on the *CR* record for a CRM analysis. For the annual cycle option, if $CR1$ exceeds 12 months, the *CR* record parameter $CR3$ may be applied to limit the *SIM* simulation results recorded in the CRM file to the last 12 months of each simulation sequence or to a specified 12 months of each simulation sequence.

A *5CRM* record activates the CRM mode of analysis. The *2REL* record diversion or hydropower reliability tables, *2RES* reservoir storage tables, and *2FRE* and *2FRQ* record flow and storage frequency tables are used to display the results of either CRM or conventional non-CRM analyses. Additional routines activated by the *5CR1* and *5CR2* records described later in this

chapter develop the storage-flow-frequency (SFF) or flow-frequency (FF) relationship and incremental probability (IP) array used in the CRM probability distribution option for assigning probabilities to the multiple simulation sequences. Without the *5CR1* and *5CR2* records, all of the simulation sequences are weighted equally in applying Equations 8.2–8.7. The format of the tables created with the *2REL*, *2FRE*, *2FRQ*, and *2RES* records are the same with or without the probability distribution option routines activated by the *5CR1* and *5CR2* records, though the numerical values are of course dependent upon the options adopted for the computations. Table headings include information from the *SIM CR* record regarding organization of the CRM simulation sequences.

5CRM, *5CR1*, *5CR2*, and *5COR* records are the only *TABLES* input records used solely for conditional reliability modeling. The *5CRM* record simply tells *TABLES* to open a *SIM* CRM output file in preparation for performing CRM analyses. The *5CR1* and *5CR2* records control the optional routines for assigning probabilities to the simulation sequences. The *5COR* record is used to compute correlation coefficients that measure the degree of linear correlation between naturalized flow volumes and preceding reservoir storage volumes at selected control points. The correlation coefficients provide information that is useful in selecting reservoirs, control points, time periods, and computational options for use in the procedures that assign probabilities to the multiple simulation sequences. The *5CRM* record is the only extra record required for conditional reliability modeling if the simulation sequences are weighted equally, with each sequence counted once in the frequency and reliability analysis counts.

Example 8.1 Based on the Equal-Weight Approach

Examples presented in this chapter are expanded versions of the example in the *Fundamentals Manual*. The system consists of eleven control points, six reservoirs, and 30 water rights. The five CRM examples in Chapter 8 consist of converting the conventional simulation presented in the *Fundamentals Manual* to a conditional reliability model. Storage frequencies and water supply reliabilities are conditioned upon specified preceding reservoir storage conditions. The 1940-2013 hydrology adopted here in this chapter was recently updated to the 1940-2016 period-of-analysis reflected in the 2018 version of the *Fundamentals Manual*.

The default CRM equal-weight option is implicitly adopted for the conditional reliability analysis of the following CRM Examples 8.1, 8.2, and 8.3, meaning that each of the *N* multiple short-term hydrologic sequences is equally-weighted or counted once in applying Equations 8.2, 8.3, and 8.4. A *SIM CR* record and *TABLES 5CRM* record are the only additional input records required to convert from the conventional long-term simulation mode to the short-term CRM mode using the equal-weight option. CRM Examples 8.4 and 8.5 presented later in this chapter apply the probability array approach that employs *5CR1* and *5CR2* records. The five CRM examples use the same *SIM* input dataset (DAT, FLO, and EVA files) with different variations of the *CR* record and adopt various *TABLES* modeling capabilities and associated input records.

The *SIM* input dataset for the example in the *Fundamentals Manual* consists of DAT, FLO, and EVA files. The five CRM examples use the same FLO and EVA files with an extended 1940-2013 period-of-analysis. For Example 8.1, the following *CR* record is inserted following the *JO* record in the DAT file shown in the *Fundamentals Manual*.

CR 12 4 0 0.25

The parameters entered on the *CR* record are defined by Table 8.1 presented earlier in this chapter. The *CR* record in this example divides the 1940-2013 period-of-analysis into 73 twelve-month hydrologic sequences extending from April (month 4) through March (month 3). Although not activated in this example, *JD* record ICHECK option 10 provides a listing in the *SIM* message file showing the subdivision of months into hydrologic simulation sequences.

The CR2 value of 4 means that each of the 73 simulations begins in April with the same user-specified beginning-of-April reservoir storage contents. Although several options are available for specifying beginning-of-simulation storage, the example adopts the combined options of the *SIM* default of starting at full to capacity which is modified by the CR4 multiplier factor of 0.25. The reservoirs all have beginning-of-month storage contents for each April of 25.0 percent of their storage capacities.

The initial few output records of the *SIM* simulation results output file, with filename extension CRM, is reproduced as Table 8.4. The CRM file contains *SIM* simulation results for months 4 through 3 (April through March) for 73 years (April 1940 – March 2013). The variables are defined in Tables 5.2-5.5 of this *Reference Manual*. CRM and OUT files contain the same variables in the same format. Program *TABLES* reads the CRM file and develops a TOU file in accordance with specifications provided by a TIN file as explained in the *Users Manual*.

Table 8.4
Beginning of *SIM* Output CRM File for the CRM Example

WRAP-SIM (August 2015 Version) CRM Output File
SIM Input File CrmExam.DAT
CRM Example 8.1 in Chapter 8 of Reference Manual
Fundamentals Manual Example Converted to CRM by Adding CR Record

1940	74	11	29	6	12	4	0	0.250	0										
IF 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	IF-1	295.89	0.00	0.00	0.00					
IF 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	IF-2	9863.01	0.00	0.00	0.00					
1940 4	0.000	4320.000	-292.83	80752.83	36755.00	36755.00	0.00	0.00	0.00	WR-6WacoLake		1512.00	0.00						
1940 4	0.000	705.600	1094.96	157531.44	16772.00	16772.00	0.00	0.00	0.00	WR-1 EK		246.96	0.00						
1940 4	0.000	20375.752	1034.60	137216.06	0.00	0.00	0.00	0.00	0.00	WR-2 EK		0.00	0.00						
1940 4	0.000	361.600	0.00	0.00	361.60	110479.30	0.00	0.00	0.00	WR-14 Cameron		36.16	0.00						
1940 4	0.000	1104.000	0.00	0.00	1104.00	178427.66	0.00	0.00	0.00	WR-20 Bryan		55.20	0.00						
1940 4	0.000	1587.200	0.00	0.00	1587.20	172890.56	0.00	0.00	0.00	WR-22 Hemp		0.00	0.00						
1940 4	0.000	1033.600	0.00	0.00	1033.60	77913.92	0.00	0.00	0.00	WR-16WacoGage		0.00	0.00						
1940 4	0.000	1433.600	0.00	0.00	1433.60	101203.09	0.00	0.00	0.00	WR-17Highbank		0.00	0.00						
1940 4	0.000	1765.400	0.00	0.00	1765.40	110117.70	0.00	0.00	0.00	WR-13 Cameron		882.70	0.00						
1940 4	0.000	3783.000	0.00	0.00	3783.00	171571.44	0.00	0.00	0.00	WR-19 Bryan		2458.95	0.00						
1940 4	0.000	9273.200	0.00	0.00	9273.20	163593.73	0.00	0.00	0.00	WR-21 Hemp		0.00	0.00						
1940 4	0.000	5958.720	-63.95	138440.23	29935.00	29935.00	0.00	0.00	0.00	WR-8 Belton		2681.42	0.00						
1940 4	0.000	8108.717	-62.77	130330.34	0.00	0.00	0.00	0.00	0.00	WR-9 Belton		1621.74	0.00						
1940 4	0.000	1768.859	3.45	11521.69	4019.00	4019.00	0.00	0.00	0.00	WR-10 George		849.05	0.00						
1940 4	0.000	2900.901	-65.94	23333.24	9793.20	9793.20	0.00	0.00	0.00	WR-11 Granger		1160.36	0.00						
1940 4	1296.000	1296.000	-557.95	183045.28	25712.33	25712.33	0.00	0.00	0.00	WR-3 Whitney		0.00	0.00						
1940 4	0.000	2947.200	0.00	0.00	2947.20	67678.80	0.00	0.00	0.00	WR-12 Cameron		1031.52	0.00						
1940 4	0.000	1754.354	0.00	0.00	1754.35	91354.15	0.00	0.00	0.00	WR-18 Bryan		701.74	0.00						
1940 4	0.000	1497.600	-291.30	79253.70	0.00	0.00	0.00	0.00	0.00	WR-7WacoLake		599.04	0.00						
1940 4	0.000	6078.078	0.00	0.00	6078.08	64731.61	0.00	0.00	0.00	WR-15 SystemC		2127.33	0.00						
1940 4	0.000	2384.000	0.00	0.00	2384.00	81647.02	0.00	0.00	0.00	WR-23 Hemp		0.00	0.00						
1940 4	0.000	62162.160	0.00	0.00	62162.16	79263.02	0.00	0.00	0.00	WR-24 SystemH		0.00	0.00						
1940 4	0.000	0.000	-557.95	183045.28	0.00	0.00	0.00	0.00	0.00	WR-5 Refill		0.00	0.00						
1940 4	0.000	0.000	1034.60	137216.06	0.00	0.00	0.00	0.00	0.00	WR-25 Refill		0.00	0.00						
1940 4	0.000	0.000	-62.77	130330.34	0.00	0.00	0.00	0.00	0.00	WR-26 Refill		0.00	0.00						
1940 4	0.000	0.000	3.45	11521.69	0.00	0.00	0.00	0.00	0.00	WR-27 Refill		0.00	0.00						
1940 4	0.000	0.000	-65.94	23333.24	0.00	0.00	0.00	0.00	0.00	WR-28 Refill		0.00	0.00						
EK	0.000	21081.352	1034.60	137216.06	16772.00	0.00	0.00	16772.00	0.00	1023.	0.	0.	0.0						
Whit	1296.000	1296.000	-557.95	183045.28	25712.33	0.00	233.24	41228.00	0.00	373.	2.	0.	0.0						

The *TABLES* TIN input file for Example 8.1 is reproduced as Table 8.5. The *5CRM* record activates the conditional reliability modeling (CRM) mode, with *TABLES* reading a *SIM* output file with extension CRM rather than OUT. CRM information is also included in the table headings generated by *TABLES*. Without the *5CRI* and *5CR2* records discussed later in this chapter, the *TABLES* computational routines are the same for the CRM application as with a conventional simulation. Of course, the reliabilities and frequencies in the example are conditioned upon all reservoirs having storage contents of 25 percent of capacity at the beginning of April.

Table 8.5
TABLES Input TIN File for CRM Example 8.1

```

** TABLES Input File CrmExam1.TIN
** CRM Example 8.1 in Chapter 8 of Reference Manual
5CRM
****      1          2          3          4          5          6
****567890123456789012345678901234567890123456789012345678901234
****-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!
**      Reliability Tables
2REL    0    0    1
2REL    0    0    0    0    0    0    1
****-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!
**      Frequency Tables
2FRE    2
2FRE    2    9    0    2
2FRE    6    6
2FRE    6    9
2FRE    6    3
2FRQ    6    3    5  Belton  50000. 100000. 200000. 400000. 450000.
****-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!
**      Reservoir Content, Drawdown, and Reliability Tables
2RES    4    6    6      PK      Whit      WacoL      Belton      George      Grang
2RES                570240. 627100. 192100. 457600. 37100. 65500.
2RES                0. 379000. 580. 0. 240. 220.
2RES    4    9    6      PK      Whit      WacoL      Belton      George      Grang
2RES                570240. 627100. 192100. 457600. 37100. 65500.
2RES                0. 379000. 580. 0. 240. 220.
****-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!
**      Reservoir Storage Table
UNIT                APR
2STO    1    0    0    2    1
IDEN    Grang
ENDF

```

The two reliability tables in Table 8.6 are reproduced from the TOU file created by *TABLES* in accordance with the *2REL* records shown in Table 8.5. With the exception of the CRM information added to the headings, these tables have the same format for either CRM or conventional analyses. The first reliability table in Table 8.6 shows reliabilities for each of the water rights. The second table shows reliabilities for the aggregation of all water rights at each control point. The reliabilities in the two tables are associated with meeting water supply diversion requirements during the 12-month period from April through March given that reservoir storage contents are at 25 percent of capacity at the beginning of April.

As an example of interpreting reliabilities, water right WR-1 has a diversion target of 9,800 acre-feet during the 12-month period April-March. The period reliability of 96.46% in the table above means that the monthly targets are fully supplied during 96.46% of the 876 months simulated. The volume reliability of 97.33% represents the percentage of the total target volume that is supplied during the 876 months. At least 97.0% of the monthly target is met during 90% of the 876 months simulated. The annual diversion was at least 78.1% and 90.4% of the 9,800 acre-feet target during 100% and 90% of the 73 annual April-March sequences.

Reliability tables may also be developed for a specified month such as August. With reliability tables generated for a specified month, only diversion data for that month is used in computing the values shown in the second through 12th columns of the table. However, the 13th through 18th columns are annual period reliabilities for the year or entire sequence length.

Table 8.6
Reliability Tables for CRM Example 8.1 Created with 2REL Records

RELIABILITY SUMMARY FOR SELECTED WATER RIGHTS

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 4

Length of simulation period (CR1) is 12 months

Number of simulations and months = 73 and 876 (CR3= 0)

Initial storage multiplier (CR4) = 0.250

NAME	TARGET	MEAN	*RELIABILITY*	PERCENTAGE OF MONTHS								PERCENTAGE OF SEQUENCES						
	DIVERSION (AC-FT/SQ)	SHORTAGE (AC-FT/SQ)	PERIOD VOLUME (%)	WITH DIVERSIONS	EQUALING OR EXCEEDING	PERCENTAGE OF TARGET	DIVERSION AMOUNT	100%	95%	90%	75%	50%	100%	98%	95%	90%	75%	50%
WR-6	60000.0	75.33	99.77	99.87	99.8	99.8	99.8	99.8	99.9	100.0	98.6	98.6	98.6	100.0	100.0	100.0	100.0	100.0
WR-1	9800.0	261.79	96.46	97.33	96.5	96.8	97.0	97.3	97.4	97.5	97.7	78.1	82.2	83.6	90.4	95.9	100.0	100.0
WR-2	245000.0	17003.53	90.30	93.06	90.3	90.4	90.5	91.4	92.6	93.7	96.2	67.1	67.1	69.9	75.3	86.3	100.0	100.0
WR-14	11300.0	114.07	98.86	98.99	98.9	99.0	99.0	99.1	99.1	99.2	99.2	89.0	90.4	93.2	97.3	98.6	100.0	100.0
WR-20	34500.0	554.80	98.86	98.39	98.9	98.9	99.0	99.0	99.2	99.3	99.3	86.3	87.7	89.0	95.9	97.3	100.0	100.0
WR-22	49600.0	1885.27	97.72	96.20	97.7	97.7	97.7	97.9	98.4	98.6	99.3	79.5	79.5	83.6	86.3	94.5	100.0	100.0
WR-16	32300.0	4217.61	92.01	86.94	92.0	92.5	92.8	93.2	94.1	94.7	95.1	47.9	56.2	57.5	61.6	72.6	93.2	93.2
WR-17	44800.0	7644.13	90.75	82.94	90.8	91.0	91.3	92.1	93.2	94.5	95.4	46.6	47.9	49.3	50.7	68.5	90.4	90.4
WR-13	18200.0	995.22	95.21	94.53	95.2	95.2	95.3	95.7	96.0	96.1	96.1	67.1	68.5	69.9	72.6	91.8	100.0	100.0
WR-19	39000.0	2551.74	94.86	93.46	94.9	94.9	94.9	95.1	95.2	95.3	95.8	65.8	65.8	65.8	68.5	90.4	100.0	100.0
WR-21	95600.0	7905.99	92.69	91.73	92.7	92.9	92.9	93.0	93.8	94.6	95.3	57.5	58.9	61.6	67.1	87.7	98.6	98.6
WR-8	82760.0	8020.43	88.47	90.31	88.5	88.7	88.9	89.5	90.4	91.4	92.7	63.0	63.0	65.8	68.5	80.8	97.3	97.3
WR-9	97500.0	12261.04	86.19	87.42	86.2	86.3	86.3	86.3	86.5	87.1	88.4	61.6	61.6	63.0	63.0	75.3	94.5	94.5
WR-10	25610.0	4877.24	75.57	80.96	75.6	75.9	76.4	77.6	80.0	84.2	92.4	35.6	37.0	39.7	46.6	65.8	86.3	86.3
WR-11	42000.0	5067.52	83.56	87.93	83.6	83.9	84.0	86.0	88.7	91.2	94.4	56.2	56.2	57.5	60.3	78.1	97.3	97.3
WR-3	18000.0	8904.52	52.28	50.53	52.3	52.3	52.3	52.4	52.5	52.6	52.7	8.2	8.2	8.2	24.7	38.4	47.9	47.9
WR-12	92100.0	34340.93	79.57	62.71	79.6	80.0	80.3	81.3	84.0	86.2	89.6	13.7	15.1	16.4	19.2	38.4	61.6	61.6
WR-18	25400.0	4655.06	84.13	81.67	84.1	84.2	84.2	84.5	85.0	85.2	85.5	37.0	37.0	39.7	42.5	60.3	94.5	94.5
WR-7	20800.0	52.80	99.66	99.75	99.7	99.7	99.7	99.7	99.7	99.8	99.8	97.3	97.3	98.6	98.6	100.0	100.0	100.0
WR-15	88000.0	6733.92	90.98	92.35	91.0	91.3	91.7	92.1	92.9	93.7	94.4	64.4	65.8	68.5	75.3	84.9	98.6	98.6
WR-23	74500.0	27795.32	81.51	62.69	81.5	81.5	81.6	82.0	83.1	84.2	85.0	26.0	26.0	27.4	32.9	39.7	56.2	56.2
WR-24	900000.0	74610.71	89.38	91.71	89.4	89.5	89.5	90.4	91.6	94.3	96.5	64.4	64.4	65.8	75.3	82.2	97.3	97.3
WR-5	This water right has no diversion target.																	
WR-25	This water right has no diversion target.																	
WR-26	This water right has no diversion target.																	
WR-27	This water right has no diversion target.																	
WR-28	This water right has no diversion target.																	
Total	2106770.0	230529.00	89.06															

Table 8.6 (Continued)
Reliability Tables for CRM Example 8.1 Created with 2REL Records

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 4

Length of simulation period (CR1) is 12 months.

Number of simulations and months = 73 and 876 (CR3= 0)

Initial storage multiplier (CR4) = 0.250

NAME	TARGET	MEAN	*RELIABILITY*		+++++++ PERCENTAGE OF MONTHS ++++++								----- PERCENTAGE OF SEQUENCES -----							
	DIVERSION (AC-FT/SQ)	SHORTAGE (AC-FT/SQ)	PERIOD (%)	VOLUME (%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%		
EK	254800.0	17265.32	90.30	93.22	90.3	90.4	90.5	91.4	92.7	93.9	97.6	67.1	67.1	69.9	75.3	86.3	100.0	100.0		
Whit	18000.0	8904.52	52.28	50.53	52.3	52.3	52.3	52.4	52.5	52.6	52.7	8.2	8.2	8.2	24.7	38.4	47.9	83.6		
WacoL	80800.0	128.13	99.66	99.84	99.7	99.7	99.7	99.8	99.8	99.9	100.0	97.3	98.6	98.6	98.6	100.0	100.0	100.0		
WacoG	32300.0	4217.61	92.01	86.94	92.0	92.5	92.8	93.2	94.1	94.7	95.1	47.9	56.2	57.5	61.6	72.6	93.2	100.0		
High	44800.0	7644.13	90.75	82.94	90.8	91.0	91.3	92.1	93.2	94.5	95.4	46.6	47.9	49.3	50.7	68.5	90.4	100.0		
Belton	180260.0	20281.47	86.19	88.75	86.2	86.3	86.3	86.5	87.8	90.3	92.5	61.6	61.6	63.0	65.8	78.1	97.3	100.0		
George	25610.0	4877.24	75.57	80.96	75.6	75.9	76.4	77.6	80.0	84.2	92.4	35.6	37.0	39.7	46.6	65.8	86.3	100.0		
Grang	42000.0	5067.52	83.56	87.93	83.6	83.9	84.0	86.0	88.7	91.2	94.4	56.2	56.2	57.5	60.3	78.1	97.3	100.0		
Camer	209600.0	42184.14	76.94	79.87	76.9	77.9	78.4	81.1	86.8	94.2	99.4	13.7	15.1	19.2	32.9	65.8	91.8	100.0		
Bryan	98900.0	7761.60	84.13	92.15	84.1	84.4	85.0	91.4	98.1	99.1	99.3	37.0	41.1	53.4	64.4	93.2	100.0	100.0		
Hemp	1119699.2	112197.34	77.28	89.98	77.3	79.3	82.2	89.6	91.9	95.2	99.7	26.0	43.8	57.5	68.5	84.9	97.3	100.0		
Total	2106769.2	230529.02																		

SHORTAGE METRICS FOR SELECTED CONTROL POINTS

NAME	MAXIMUM SHORTAGE (AC-FT)	VULNERABILITY (AC-FT/SQ)	RESILIENCY (MONTHS^-1)	AVERAGE SEVERITY (AC-FT/SQ)	SHORTAGE INDEX (MONTHS^-1)	MEAN NUMBER OF FAILURES PER SEQUENCE	MAXIMUM NUMBER OF CONSECUTIVE SHORTAGES (MONTHS)
EK	28896.88	20505.943	0.327	46571.92	1.84	0.40	7
Whit	2124.00	1884.090	0.168	9253.09	37.51	1.04	12
WacoL	4601.20	2771.731	0.667	4676.62	0.02	0.03	2
WacoG	9819.20	5667.122	0.650	7302.55	5.49	0.66	4
High	13619.20	9705.118	0.561	12918.05	7.34	0.64	5
Belton	20805.26	16510.234	0.241	50731.51	4.20	0.41	8
George	2845.56	2230.329	0.236	7104.70	8.02	0.73	10
Grang	4666.67	3776.070	0.240	10765.22	4.21	0.52	8
Camer	40251.43	22819.775	0.387	39897.47	6.83	1.08	9
Bryan	18302.22	5948.781	0.442	9105.40	1.51	0.88	5
Hemp	140720.78	55097.367	0.339	113053.39	2.99	1.12	9

The 1 in column 32 of the second 2REL record in the TIN file of Table 8.5 activates an option that creates an auxiliary table of shortage metrics along with the reliability table. Shortage refers to a failure to supply a diversion target during a month of the simulation. The quantities in the above shortage metrics table are defined earlier in this chapter.

The two flow-frequency tables in Table 8.7, created with the 2FRE records shown in Table 8.5, illustrate the alternative row and column formats. The first regulated flow frequency table in Table 8.7 shows the percentage-of-time or likelihood of monthly flow volumes equaling or exceeding various amounts during the period April through March conditioned upon storage in all reservoirs being at 25% of capacity at the beginning of April. The second table in Table 8.7 shows frequencies for monthly regulated flow volumes during September given the preceding storage conditions at the beginning of April.

Table 8.7
Flow Frequency Tables for CRM Example 8.1 Created with 2FRE Records

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 4

Length of simulation period (CR1) is 12 months.

Number of simulations and months = 73 and 876 (CR3= 0)

Initial storage multiplier (CR4) = 0.250

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
EK	31737.5	99197.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	29292.	101723.	1782155.
Whit	43650.6	144010.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	6409.	46149.	104143.	2791217.
WacoL	15193.6	47571.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	911.	44544.	526063.
WacoG	83631.4	187648.	0.0	0.0	0.0	0.0	2965.9	14037.2	31194.	40942.	56211.	89085.	155801.	3217254.
High	111388.6	216512.	0.0	0.0	0.0	0.0	5161.8	25414.0	43799.	58773.	76735.	107359.	238643.	3438270.
Belton	15633.1	46519.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6942.	49948.	584895.
George	2459.7	7597.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	7721.	66133.
Grang	9431.2	22090.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	66.	8383.	30998.	200100.
Carer	76112.7	138970.	0.0	295.9	295.9	303.8	305.8	5706.4	16120.	26480.	42665.	82560.	205372.	1392558.
Bryan	216577.2	373527.	0.0	0.0	4484.7	9325.7	29873.2	59646.8	85367.	100580.	117617.	213172.	512423.	4484522.
Hemp	249196.9	479531.	8243.2	9205.5	9863.0	9863.0	9863.0	10191.8	10192.	36383.	94995.	299734.	753969.	5418992.

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS FOR MONTH 9

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 4

Length of simulation period (CR1) is 12 months.

Number of simulations and months = 73 and 876 (CR3= 0)

Initial storage multiplier (CR4) = 0.250

CP	EK	Whit	WacoL	WacoG	High	Belton	George	Grang	Carer	Bryan	Hemp
Mean	42980.83	40937.29	4002.01	59196.05	67578.02	10205.73	532.12	3855.03	31291.64	105331.24	75669.11
Std Dev	63056.57	52201.64	15458.51	52298.46	57806.53	23683.16	3087.83	11089.15	48833.13	89656.13	183988.66
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9863.00
99.5%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	108.00	0.00	9863.00
99%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	216.00	0.00	9863.01
98%	0.00	0.00	0.00	0.00	209.93	0.00	0.00	0.00	295.89	2224.01	9863.01
95%	0.00	0.00	0.00	630.98	4103.99	0.00	0.00	0.00	295.89	8275.48	9863.01
90%	0.00	0.00	0.00	3823.60	6069.54	0.00	0.00	0.00	295.89	12321.23	9863.01
85%	0.00	0.00	0.00	6806.62	10647.12	0.00	0.00	0.00	295.89	34132.43	9863.01
80%	0.00	0.00	0.00	11663.52	15581.06	0.00	0.00	0.00	657.51	45042.57	9863.01
75%	0.00	0.00	0.00	14229.88	23213.30	0.00	0.00	0.00	1839.24	63273.83	9863.01
70%	0.00	0.00	0.00	23026.91	30431.13	0.00	0.00	0.00	2419.99	77523.79	9863.01
60%	0.00	3719.10	0.00	35736.62	43769.80	0.00	0.00	0.00	6565.89	92900.10	9863.01
50%	15336.24	15049.38	0.00	58695.04	69911.36	0.00	0.00	0.00	11854.81	97832.38	9863.02
40%	30722.53	35022.43	0.00	72909.84	80904.00	400.84	0.00	0.00	20845.98	102556.41	9863.02
30%	71093.30	61649.40	0.00	81119.57	94117.31	4410.24	0.00	5.50	33232.04	110168.34	9863.02
25%	85518.51	87247.64	0.00	93432.80	95920.62	8843.01	0.00	184.75	40877.28	116860.30	30479.93
20%	100718.04	95518.31	0.00	96531.66	98982.54	9934.76	0.00	1290.57	49653.31	133351.20	63274.50
15%	101723.45	96224.14	0.00	99876.38	107624.95	19968.72	0.00	6487.39	69729.94	147235.67	101837.08
10%	101723.45	100756.81	3588.61	115665.10	131361.62	27770.98	57.10	11635.14	87670.93	168708.77	246094.23
5%	174628.30	145829.30	51471.29	133490.95	166728.67	86791.80	1840.11	37003.21	132895.03	313260.31	569948.81
2%	298590.44	209846.25	78064.48	253882.94	290055.31	96690.27	17283.14	52412.33	247777.11	488396.53	888680.88
1%	326553.28	226274.33	81597.80	319076.62	338762.88	99476.24	25001.44	63603.52	249344.44	503522.66	905417.25
0.5%	326553.28	226274.33	81597.80	319076.62	338762.88	99476.24	25001.44	63603.52	249344.44	503522.66	905417.25
Maximum	326553.28	226274.33	81597.80	319076.62	338762.88	99476.24	25001.44	63603.52	249344.44	503522.66	905417.25

Table 8.8
Storage Frequency Tables for CRM Example 8.1 Created with 2FRE Records

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 6

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 4

Length of simulation period (CR1) is 12 months.

Number of simulations and months = 73 and 876 (CR3= 0)

Initial storage multiplier (CR4) = 0.250

RESERVOIR	STANDARD		PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	274433.	192398.	0.	0.	0.	0.	23638.	107852.	207815.	250403.	332598.	431168.	570240.	570240.
Whit	369903.	158866.	147820.	149532.	150368.	173921.	212404.	231756.	276234.	331400.	378941.	498065.	627100.	627100.
WacoL	120275.	60465.	35632.	36624.	37412.	38335.	42907.	60685.	94988.	118444.	150338.	192100.	192100.	192100.
Belton	206580.	153073.	0.	0.	0.	0.	39886.	85882.	115346.	158477.	216169.	320874.	457600.	457600.
George	16512.	14472.	0.	0.	0.	0.	0.	3826.	7309.	12706.	19454.	34378.	37100.	37100.
Grang	32147.	26662.	0.	0.	0.	0.	0.	7815.	15624.	20741.	47452.	65500.	65500.	65500.
Total	1019850.	537902.	188511.	189331.	190524.	230428.	380501.	571751.	788525.	965851.	1168131.	1456516.	1824394.	1949640.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 9

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 4

Length of simulation period (CR1) is 12 months.

Number of simulations and months = 73 and 876 (CR3= 0)

Initial storage multiplier (CR4) = 0.250

RESERVOIR	STANDARD		PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	229464.	198796.	0.	0.	0.	0.	0.	26770.	140829.	203544.	312433.	426652.	505505.	570240.
Whit	379396.	140844.	134439.	137342.	142632.	196503.	216042.	264016.	337724.	376299.	398603.	504282.	608717.	627100.
WacoL	111807.	62827.	5304.	6003.	6721.	19374.	36948.	54598.	79484.	115387.	156889.	172592.	191940.	192100.
Belton	145032.	152399.	0.	0.	0.	0.	0.	0.	53350.	96319.	158374.	265014.	420413.	457600.
George	8248.	12188.	0.	0.	0.	0.	0.	0.	0.	0.	2552.	15709.	32546.	35352.
Grang	17107.	21980.	0.	0.	0.	0.	0.	0.	1720.	5175.	14710.	29446.	58370.	65500.
Total	891054.	526971.	139744.	153740.	170455.	246501.	280969.	416755.	625943.	839818.	1021778.	1354404.	1609370.	1934023.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 3

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 4

Length of simulation period (CR1) is 12 months.

Number of simulations and months = 73 and 876 (CR3= 0)

Initial storage multiplier (CR4) = 0.250

RESERVOIR	STANDARD		PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	263996.	191762.	0.	0.	0.	0.	0.	100990.	202781.	288471.	328274.	422820.	564043.	570240.
Whit	480842.	123476.	224588.	246840.	255580.	281222.	332188.	379000.	411238.	491683.	541536.	627100.	627100.	627100.
WacoL	149334.	59121.	7825.	14835.	18490.	29381.	47939.	111877.	175062.	190567.	192100.	192100.	192100.	192100.
Belton	210638.	176758.	0.	0.	0.	0.	125.	40274.	115098.	195270.	259946.	417350.	457600.	457600.
George	17847.	15589.	0.	0.	0.	0.	0.	207.	10591.	17309.	25752.	36964.	37100.	37100.
Grang	39664.	28001.	0.	0.	0.	0.	5.	10193.	26925.	58372.	65097.	65500.	65500.	65500.
Total	1162319.	521329.	260551.	269271.	283339.	407852.	474224.	755466.	1050418.	1140584.	1384675.	1609613.	1932004.	1949640.

Table 8.8 presents end-of-month reservoir storage frequency tables for June, September, and March (months 6, 9, and 3). The exceedance frequency estimates reflect given storage levels at the beginning of April in all reservoirs equal to 25% of their storage capacity. There is a 60% probability that the end-of-June storage contents of Belton Reservoir will equal or exceed 115,346 acre-feet given that the storage contents at the beginning of April is 114,400 acre-feet. For Belton Reservoir, Table 8.8 indicates a 60% probability that the storage at the end of September will equal or exceed 53,350 ac-ft or at the end of March will equal or exceed 115,098 acre-feet conditioned upon the preceding beginning-of-April storage of 114,400 acre-feet.

The frequency table in Table 8.9 reproduced from the *TABLES* output TOU file was created in accordance with the *2FRQ* record shown in Table 8.5. The frequency relationship is for end-of-month storage for March (month 3) in Belton Reservoir given that storage 12 months earlier at the beginning of April was at 25% of the reservoir capacity for all six reservoirs including Belton. Given that storage in Belton Reservoir is at 25% of its capacity of 457,600 acre-feet at the beginning of April, there is an estimated probability of 0.7123 that the storage volume will be at least 50,000 acre-feet twelve months later and probability of 0.2329 that the storage will equal or exceed 450,000 acre-feet twelve months later.

Table 8.9
Frequency Table for CRM Example 8.1 Created with 2FRQ Record

STORAGE-FREQUENCY FOR RESERVOIR Belton FOR MONTH 3

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 4

Length of simulation period (CR1) is 12 months.

Number of simulations and months = 73 and 876 (CR3= 0)

Initial storage multiplier (CR4) = 0.250

STORAGE	FREQ (%)	STORAGE	FREQ (%)	STORAGE	FREQ (%)	STORAGE	FREQ (%)	STORAGE	FREQ (%)
50000.0	71.23	100000.0	63.01	200000.0	49.32	400000.0	24.66	450000.0	23.29

The *2RES* records create the storage drawdown and storage reliability tables shown in Table 8.10. The storage reliability table for June (month 6) shows that with PK Reservoir having a storage content of 25% of its capacity at the beginning of April, there is an estimated 15.1% frequency, probability, or likelihood that PK Reservoir will be 100% full to capacity at the end of June and a 45.2% probability that the end-of-June storage content will be at least 50% of capacity. The table shows an 82.2% percentage-of-time or probability of PK Reservoir having an end-of-June storage volume of at least 10% of storage capacity given that the preceding beginning-of-April storage is 25% of capacity.

The storage table for Granger Reservoir shown in Table 8.11 was created with a *2STO* record. Each row represents one simulation sequence. The *UNIT* record is included in the *TIN* file of Table 8.5 so that the Table 8.11 table headings will begin with April rather than January.

Hundreds of tables may be generated to provide an array of information of interest in a particular decision-support situation. Tables 8.5 through 8.11 provide a small illustrative sampling

of alternative contents and formats of reliability and frequency tables. 2STO and similar time series records also write any of the SIM simulation results time series data as HEC-DSS records for plotting with HEC-DSSVue.

Table 8.10
Reservoir Storage Table for CRM Example 8.1 Created with 2RES Records

RESERVOIR STORAGE DRAWDOWN DURATION FOR MONTH 6

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 4

Length of simulation period (CR1) is 12 months.

Initial storage multiplier (CR4) = 0.250

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	NUMBER OF PERIODS WITH DRAWDOWNS EQUALING OR EXCEEDING PERCENT OF ZONE STORAGE CAPACITY								
				0%	2%	5%	10%	25%	50%	75%	90%	100%
PK	274432.44	0.	570240.	73.	62.	62.	59.	55.	40.	21.	13.	5.
Whit	369903.00	379000.	627100.	73.	60.	60.	60.	58.	56.	49.	47.	45.
WacoL	120274.51	580.	192100.	73.	49.	49.	49.	43.	30.	9.	0.	0.
Belton	206579.25	0.	457600.	73.	60.	60.	59.	57.	46.	30.	9.	5.
George	16511.73	240.	37100.	73.	56.	56.	54.	51.	43.	34.	19.	12.
Grang	32146.75	220.	65500.	73.	51.	51.	50.	46.	40.	31.	17.	11.

RESERVOIR STORAGE RELIABILITY FOR MONTH 6

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 4

Length of simulation period (CR1) is 12 months.

Initial storage multiplier (CR4) = 0.250

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING PERCENTAGE OF STORAGE CAPACITY								
				100%	98%	95%	90%	75%	50%	25%	10%	>0%
PK	274432.44	0.	570240.	15.1	15.1	15.1	19.2	24.7	45.2	71.2	82.2	100.0
Whit	369903.00	379000.	627100.	16.4	17.8	17.8	17.8	20.5	23.3	32.9	35.6	39.7
WacoL	120274.51	580.	192100.	28.8	32.9	32.9	32.9	41.1	58.9	87.7	100.0	100.0
Belton	206579.25	0.	457600.	17.8	17.8	17.8	19.2	21.9	37.0	58.9	87.7	100.0
George	16511.73	240.	37100.	21.9	23.3	23.3	26.0	30.1	41.1	53.4	74.0	83.6
Grang	32146.75	220.	65500.	30.1	30.1	30.1	31.5	37.0	45.2	57.5	76.7	84.9

RESERVOIR STORAGE DRAWDOWN DURATION FOR MONTH 9

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 4

Length of simulation period (CR1) is 12 months.

Initial storage multiplier (CR4) = 0.250

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	NUMBER OF PERIODS WITH DRAWDOWNS EQUALING OR EXCEEDING PERCENT OF ZONE STORAGE CAPACITY								
				0%	2%	5%	10%	25%	50%	75%	90%	100%
PK	229463.94	0.	570240.	73.	68.	68.	68.	55.	42.	30.	25.	16.
Whit	379395.12	379000.	627100.	73.	68.	67.	65.	63.	55.	50.	46.	40.
WacoL	111806.91	580.	192100.	73.	64.	59.	56.	43.	35.	16.	4.	0.
Belton	145031.41	0.	457600.	73.	70.	69.	65.	62.	51.	40.	27.	22.
George	8248.08	240.	37100.	73.	73.	72.	71.	63.	57.	51.	45.	38.
Grang	17106.67	220.	65500.	73.	69.	69.	67.	62.	56.	47.	40.	27.

RESERVOIR STORAGE RELIABILITY FOR MONTH 9

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING PERCENTAGE OF STORAGE CAPACITY								
				100%	98%	95%	90%	75%	50%	25%	10%	>0%
PK	229463.94	0.	570240.	5.5	6.8	6.8	6.8	24.7	42.5	58.9	65.8	100.0
Whit	379395.12	379000.	627100.	6.8	6.8	8.2	11.0	13.7	24.7	31.5	37.0	49.3
WacoL	111806.91	580.	192100.	9.6	12.3	19.2	23.3	41.1	52.1	78.1	94.5	100.0
Belton	145031.41	0.	457600.	4.1	4.1	5.5	11.0	15.1	30.1	45.2	63.0	100.0
George	8248.08	240.	37100.	0.0	0.0	1.4	2.7	13.7	21.9	30.1	38.4	47.9
Grang	17106.67	220.	65500.	1.4	5.5	5.5	8.2	15.1	23.3	35.6	45.2	64.4

Table 8.11
Reservoir Storage Table for CRM Example 8.1 Created with 2STO Record

END-OF-MONTH STORAGE (AC-FT) FOR RESERVOIR Grang

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month (CR2) = 4

Length of simulation period (CR1) = 12 months

Initial storage multiplier (CR4) = 0.250

Simulation output and tables start in the 0th month (CR3) of the simulation sequences.

SEQ	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	MEAN
1	23333.2	30992.2	10298.4	49185.1	47097.1	37409.7	35729.8	65500.0	65500.0	65500.0	65500.0	65500.0	46795.4
2	65500.0	65500.0	65500.0	65500.0	63383.6	60797.8	64557.2	63627.3	63653.0	63009.9	62004.6	60403.2	63619.7
3	37452.2	45627.7	65500.0	63072.5	49933.7	57046.7	65500.0	65500.0	65500.0	65500.0	65500.0	65500.0	59302.7
4	17050.4	18282.4	15489.0	12775.8	0.0	0.0	0.0	0.0	0.0	8938.2	32333.8	63108.4	13998.2
5	28864.9	65500.0	65500.0	63538.3	0.0	3999.1	2232.1	5867.1	26791.5	59625.4	65500.0	65500.0	37743.2
6	56542.7	65500.0	65500.0	65500.0	59570.3	58546.8	58883.9	61149.6	62100.6	65500.0	65500.0	65500.0	62482.8
7	28912.6	44605.2	47662.5	34522.6	20924.7	18592.2	22321.7	41274.8	65500.0	65500.0	65500.0	65500.0	43401.4
8	28895.6	34510.4	33668.2	20711.6	18581.6	9685.5	7220.8	5689.2	4590.6	3539.0	2528.8	971.9	14216.1
9	28245.0	41906.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1160.0	5942.6
10	31450.7	32559.5	34729.0	32164.3	27866.1	24516.2	22375.2	19857.5	18732.0	17410.5	18399.9	16886.2	24745.6
11	17510.7	20646.6	20576.4	17565.7	13723.3	11297.5	7735.9	4664.6	2035.0	0.0	0.0	0.0	9646.3
12	10602.4	8735.9	5573.7	568.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2123.4
13	25383.8	40820.9	20486.5	16353.3	0.0	0.0	0.0	0.0	11933.2	13705.1	15520.7	17333.7	13461.4
14	0.0	15321.9	13332.1	9301.8	5667.8	6671.5	24144.5	24900.9	25926.9	25846.6	24813.8	17389.4	16109.8
15	14469.5	12559.1	8796.1	4918.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3395.2
16	14419.7	23569.0	26284.1	22660.7	20012.5	16533.5	13284.0	10775.0	8402.6	5857.8	3443.5	758.2	13833.4
17	13918.8	14892.2	11065.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.5	3324.3
18	65500.0	65500.0	65500.0	64448.4	60568.5	60490.0	65500.0	65500.0	65500.0	65500.0	65500.0	65500.0	64583.9
19	27813.7	42238.0	45906.1	35313.5	33038.3	37139.2	38396.9	39553.3	40572.9	40943.0	43562.2	14880.6	36613.1
20	22363.4	25058.2	19623.8	18219.1	10226.1	10336.2	65500.0	65500.0	65500.0	65500.0	65500.0	65500.0	41568.9
21	23852.7	26154.0	17057.9	5865.6	3674.5	1385.8	17238.3	28707.8	65500.0	65500.0	65500.0	65500.0	32161.4
22	22781.6	0.0	1193.0	12767.3	13256.3	15562.7	17638.1	19677.4	22089.5	23833.8	25190.9	25621.9	16634.4
23	0.0	2925.4	6726.1	6287.9	2240.3	220.1	0.0	0.0	0.0	0.0	0.0	0.0	1533.3
24	15404.0	13704.4	10013.0	6045.2	1512.1	0.0	0.0	0.0	0.0	0.0	1387.2	5007.6	4422.8
25	18407.8	0.0	0.0	0.0	0.0	1673.0	321.7	5282.9	7214.1	14131.7	46796.8	62857.6	13057.1
26	28034.0	65500.0	65500.0	65500.0	54154.2	0.0	2978.6	13781.7	35029.3	46529.6	62332.3	65500.0	42070.0
27	63942.6	65500.0	54366.6	42628.7	43713.6	53956.9	53762.6	52801.1	53061.0	11083.3	10906.6	10016.0	42978.3
28	17635.8	33090.9	20905.4	6997.0	3492.6	8178.9	0.0	9260.2	18742.6	65500.0	65500.0	65500.0	26233.6
29	37882.5	65500.0	65500.0	65500.0	54443.0	57958.9	57551.4	61100.3	65500.0	65500.0	65500.0	65500.0	60619.7
30	50444.4	65500.0	65500.0	53444.6	0.0	1905.7	3074.2	3163.4	8839.5	15726.7	33893.6	65500.0	30582.7
31	33380.2	64496.1	59090.0	0.0	0.0	2648.6	2352.2	1733.3	1285.5	709.0	0.0	0.0	13807.9
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5800.6	13457.8	15965.0	17238.6	17133.6	5799.6
33	0.0	4704.1	12135.1	0.0	0.0	0.0	0.0	9448.8	14408.0	26462.0	41312.2	56001.0	13705.9
34	40248.6	65500.0	65500.0	55665.1	14290.0	22304.8	65500.0	65500.0	65500.0	65500.0	65500.0	65500.0	54709.0
35	19093.3	46525.5	0.0	0.0	0.0	16089.7	23631.3	65500.0	65500.0	65500.0	65500.0	65500.0	36070.0
36	23192.4	65500.0	65500.0	65500.0	65500.0	27054.4	27170.4	27286.7	28091.2	28330.2	4916.7	5130.5	36097.7
37	46008.8	65500.0	65500.0	65500.0	38863.2	0.0	1574.1	5457.1	18053.9	26958.3	51901.5	62328.3	37303.8
38	65500.0	65500.0	65500.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1034.4	904.4	16536.6
39	16699.5	8136.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9055.5	32675.0	65500.0	11005.6
40	49691.2	65500.0	65500.0	65500.0	65500.0	64866.2	59763.3	58593.1	59738.8	59586.6	65500.0	65500.0	62103.3

41	19419.6	34687.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	998.9	6406.6	5126.1
42	20068.4	29612.9	65500.0	65500.0	0.0	23308.4	41326.3	49991.8	53210.5	54884.1	55556.1	56769.1	42977.3	42977.3
43	24214.2	49943.8	57019.0	45508.7	32288.7	19706.3	16979.3	16096.6	15853.3	16736.7	23834.3	40656.9	29903.1	29903.1
44	21807.3	54467.6	65500.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11814.6
45	14184.8	0.0	0.0	0.0	0.0	0.0	29218.9	34441.1	46312.8	57005.9	65500.0	65500.0	26013.6	26013.6
46	30391.6	43915.9	47729.9	35667.3	21551.5	4671.6	10573.4	24380.4	52582.9	60718.7	65500.0	65500.0	38598.6	38598.6
47	3430.2	9784.0	26042.9	24018.5	20783.9	20806.6	39837.9	48845.7	65500.0	65500.0	65500.0	65500.0	37962.5	37962.5
48	24429.5	57033.2	65500.0	65500.0	0.0	1124.8	1131.6	8026.3	13468.8	17850.6	20545.4	22714.7	24777.1	24777.1
49	7068.1	7049.3	13540.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	941.5	2383.3	2383.3
50	15952.3	48459.5	51261.3	37777.6	33662.1	29547.6	26807.3	24588.9	22373.8	21244.7	20742.7	25733.4	29845.9	29845.9
51	21114.2	50757.7	46609.4	42270.1	37397.9	33288.4	29238.8	26839.9	24329.8	43180.2	53819.8	59595.4	39036.8	39036.8
52	56272.4	65500.0	65500.0	53050.9	41293.9	41775.1	41956.6	42479.8	65500.0	65500.0	65500.0	65500.0	55819.1	55819.1
53	32181.1	65500.0	65500.0	65500.0	65500.0	64355.6	63172.8	64885.8	65500.0	65500.0	65500.0	65500.0	62382.9	62382.9
54	33900.1	65500.0	65500.0	65500.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19200.0	19200.0
55	14950.3	19026.9	16161.7	11838.1	8772.1	5100.5	13241.7	14882.8	32734.9	42603.6	46522.7	62286.5	24010.2	24010.2
56	23774.1	39995.5	50505.9	48222.6	46867.1	43812.0	40329.2	38982.5	37860.0	36398.1	34590.4	31691.1	39419.1	39419.1
57	14627.8	12080.7	0.0	0.0	0.0	29142.4	0.0	1254.7	18425.6	27957.2	54526.9	65500.0	18626.3	18626.3
58	65500.0	65500.0	65500.0	65500.0	6686.3	6086.8	7094.3	9693.9	37834.0	40933.4	65500.0	65500.0	41777.4	41777.4
59	0.0	0.0	0.0	0.0	0.0	0.0	65500.0	65500.0	65500.0	65411.3	55254.9	57148.9	31192.9	31192.9
60	15886.3	20703.1	18008.4	4384.1	0.0	0.0	0.0	0.0	0.0	8180.6	9881.7	10723.0	7313.9	7313.9
61	17035.8	17878.4	18657.2	4678.1	1131.1	0.0	20018.1	65500.0	65500.0	65500.0	65500.0	65500.0	33908.2	33908.2
62	16385.9	18366.7	0.0	0.0	0.0	5249.9	8104.3	42591.1	65500.0	65500.0	64507.8	63483.1	29140.7	29140.7
63	14249.0	11281.2	10667.0	12171.3	8418.7	2192.7	51521.8	65500.0	65500.0	65500.0	65500.0	65500.0	36500.1	36500.1
64	13790.3	9280.6	7466.3	5153.9	513.7	0.0	326.9	0.0	196.9	11481.7	46044.2	48381.2	11886.3	11886.3
65	36174.9	32626.2	65500.0	65500.0	64595.8	51421.1	65500.0	65500.0	65500.0	65500.0	65500.0	65500.0	59068.2	59068.2
66	0.0	5466.5	4145.9	0.0	2430.0	0.0	0.0	0.0	0.0	0.0	653.5	2055.9	1229.3	1229.3
67	17402.2	18852.5	14087.6	0.0	0.0	0.0	37612.7	34536.5	44530.8	65500.0	65500.0	65500.0	30293.5	30293.5
68	29513.0	65500.0	65500.0	65500.0	65500.0	65212.5	20291.4	22389.4	23164.5	22964.1	20767.5	22411.7	40726.2	40726.2
69	18224.6	19717.1	6400.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3695.2	3695.2
70	23968.7	18840.1	14733.6	9569.1	0.0	65500.0	65500.0	65500.0	65500.0	65500.0	65500.0	65500.0	43801.0	43801.0
71	15682.2	14856.3	7488.4	7563.2	3931.0	45941.6	34126.4	30382.5	27943.6	34422.6	35562.3	32624.6	24210.4	24210.4
72	13732.2	10738.3	0.0	0.0	0.0	0.0	0.0	0.0	36780.4	65500.0	65500.0	65500.0	21479.2	21479.2
73	4803.9	3621.3	228.2	0.0	0.0	3699.8	0.0	0.0	0.0	20780.0	20338.6	14417.3	5657.4	5657.4
MEAN	24802.2	34111.0	32147.0	26217.7	17158.3	17107.0	21306.1	25140.3	30292.5	33911.0	37449.9	39663.7	28275.6	28275.6

The tables in Tables 8.6, 8.7, 8.8, 8.9, 8.10, and 8.11 are from a single *TABLES* output TOU file. The computations performed by program *TABLES* for conditional reliability modeling (CRM) with the equal-weight option based on *SIM* simulation results from a CRM file are the same as conventional WRAP applications using simulation results from an OUT file. The format of the tables is also the same with either CRM or conventional applications except for the four lines added to the header that define CRM specifications from the *CR* record.

Since a CR1 of 12 months is specified on the *CR* record, 2REL, 2FRE, 2FRQ, and 2RES tables can be constructed for the aggregate of all months or for either individual month of the 12 months of the year. However, in general, tables can be developed only for the months included in the simulation sequence defined by CR1 and CR2. For example, if a simulation length CR1 of 5 months is combined with a starting month of April (CR2=4) in the *SIM* simulation, tables can be constructed by *TABLES* for only April, May, June, July, August, and September. In this case, the number of simulation sequences would be 74 rather than 73.

Each row of storage volumes in the 2STO record table of Table 8.11 represents a simulation sequence. Since CR1 is 12, end-of month storage volumes are tabulated in Table 8.11 for all 12 months of the year. If CR1 is less than 12, only those months included in the simulation sequences are tabulated in 2STO storage tables. The UNIT record allows user specification of the beginning month in the table heading.

Table 8.12 illustrates a convenient format for presenting a CRM storage-frequency relationship for a particular reservoir. The storage-frequency relationship for Granger Reservoir

presented in Table 8.12 was compiled from twelve 2FRE tables which include the frequency tables for June, September, and March (months 6, 9, 12) reproduced in Table 8.8 and additional 2FRE tables for each of the other nine months. The twelve 2FRE tables are derived from the results of a single *SIM* simulation. Program *TABLES* computed the statistics in Table 8.12 from the 73 storage volumes for each of the 12 months of the year that are tabulated in Table 8.11. Twelve 2FRE records were used to compute the frequency statistics for each of the 12 months.

Table 8.12
Storage-Frequency Relationships for Granger Reservoir for
Initial Storage Volume of 16,375 acre-feet (25 Percent of Capacity) at the Beginning of April

Month	4 Apr	5 May	6 Jun	7 Jul	8 Aug	9 Sep	10 Oct	11 Nov	12 Dec	1 Jan	2 Feb	3 Mar
Mean	24,802	34,111	32,147	26,218	17,158	17,107	21,306	25,140	30,292	33,911	37,450	39,664
St Dev	16,663	23,434	26,662	26,600	22,817	21,980	23,775	25,360	26,366	26,651	26,855	28,001
Min	0	0	0	0	0	0	0	0	0	0	0	0
99%	0	0	0	0	0	0	0	0	0	0	0	0
98%	0	0	0	0	0	0	0	0	0	0	0	0
95%	0	0	0	0	0	0	0	0	0	0	0	0
90%	5,483	4,933	0	0	0	0	0	0	0	0	0	4.64
80%	14,351	11,064	6,070	0	0	0	0	0	0	2,407	2,072	3,823
70%	15,946	17,623	10,630	4,003	0	0	0	3,020	8,284	13,483	18,284	16,686
60%	17,754	20,658	15,623	7,110	0	1,720	2,998	8,273	18,128	20,873	26,619	26,925
50%	22,085	32,593	20,741	14,565	3,584	5,175	13,362	17,887	25,128	28,144	44,803	58,372
40%	24,165	42,172	47,452	34,051	12,650	14,710	22,365	27,197	37,623	45,860	55,496	65,097
30%	28,897	51,129	65,500	48,319	22,183	23,429	34,287	41,395	53,863	65,420	65,500	65,500
20%	65,500	65,500	65,500	65,500	42,262	23,429	45,783	61,120	65,500	65,500	65,500	65,500
10%	65,500	65,500	65,500	65,500	60,269	58,370	65,217	65,500	65,500	65,500	65,500	65,500
Max	65,500	65,500	65,500	65,500	65,500	65,500	65,500	65,500	65,500	65,500	65,500	65,500

End-of-month storage volumes in acre-feet in Granger Reservoir are tabulated for each of 12 months of the year in Table 8.12 from the results of a *SIM* simulation with the beginning-of-April storage contents set at 25 percent of capacity in each of the six reservoirs. The capacity of Granger Reservoir is 65,500 acre-feet. The interpretation of the CRM storage-frequency relationship of Table 8.12 is illustrated as follows.

The June column of Table 8.12 refers to the 73 end-of-June storage volumes tabulated in Table 8.11. The mean and standard deviation of the 73 volumes are 32,147 and 26,662 acre-feet. Granger Lake is at full capacity of 65,500 ac-ft at the end of June for somewhere between 30% and 40% of the 73 simulation sequences. The end-of-June storage volume equals or exceeds 20,741 ac-ft in 50 percent of the 73 simulation sequences. Thus, the estimated probability of the storage level being at or above 20,741 ac-ft at the end of June is 50 percent if the storage content is 16,375 ac-ft at the beginning of April. The corresponding median or 50 percent exceedance frequency storage contents for the end of September and March are 5,175 and 58,372 acre-feet. There is a 60% likelihood that the Granger Reservoir storage contents will equal or exceed 1,720 ac-ft at the end of September if the storage volume is 25% of capacity at the beginning of April.

Simulation Results in CRM, TOU, SOU, and DSS Files

Conditional reliability modeling (CRM) and conventional non-CRM simulation results are recorded by *SIM* in an output file with filename extension CRM or OUT, respectively, which is read by *TABLES*. Program *SIM* generates either a CRM or OUT file, but never both, depending on whether a CR record is contained in the *SIM* input DAT file. The WRAP program *TABLES* performs frequency and reliability analyses and otherwise organizes and summarizes *SIM* simulation results from a CRM or OUT file as illustrated in the preceding Example 8.1. The tables created by *TABLES* are in the same format for either CRM or long-term non-CRM simulations. The optional CRM header information illustrated by the tables of Example 8.1 is included by default but can be omitted by an entry on the 5CRM record in the *TABLES* input TIN file. The differences in interpretation of short-term CRM versus conventional long-term frequency and reliability analyses results are discussed earlier in this chapter.

TABLES routines other than 2FRE and 2FRQ frequency and 2REL reliability analyses are limited to inclusion of results in the CRM file for each simulation sequence to not exceed 12 months. However, the complete simulation results for any CR1 sequence length including those much longer than 12 months can be recorded in SOU and DSS files created by *SIM*. *TABLES* reads *SIM*-created CRM and OUT files but does not read *SIM*-created SOU or DSS files.

The parameter CR3 on the CR record in the *SIM* input file is applicable only if the simulation period defined by CR1 is greater than 12 months. With a CR1 period of 12 months or less, all of the months of the simulation sequences are included in the CRM, SOU, and DSS output files. With CR1 greater than 12 months, CR3 options allow specification of either any 12 consecutive months or all months of the simulation sequences included in the CRM and DSS output files. The CR3 default is to include the last 12 months of each sequence in the simulation results output files. The *TABLES* frequency and reliability analyses can be applied with any CR1 simulation length, but analyses for a specific month of the year, such as August, should be performed with simulation results limited by CR3 to not exceed 12 months, though this could be the last 12 months of a longer CR1 sequence length. Frequency and reliability analysis considering all months can be meaningfully applied to simulation results of any sequence length including 12 months, less than 12 months, or greater than 12 months.

The optional output files *OF* record in the *SIM* input file allows creation of SOU and/or DSS files and/or not creating a CRM/OUT file. The defaults are to create an OUT or CRM file and to not create SOU and DSS files. The *SIM* simulation output (SOU) and data storage system (DSS) files, with filename extensions SOU and DSS, record time series of *SIM* simulation results for the same variables but in different formats. The SOU text file read by any editor consists of time series tables that include all months for which simulation computations are performed. The DSS file in binary format is read by HEC-DSSVue for plotting or various manipulations. With CRM, the DSS file contains time series of simulation results for the individual CRM sequences.

Control points, water rights, and reservoirs are selected for inclusion in OUT, CRM, SOU, and DSS files in the same manner using *JD*, *CO*, *WO*, *GO*, and *RO* input records. Most of the simulation results time series variables that can be included in an OUT or CRM file can be also included in SOU and DSS files. The 36 variables that can be included in SOU and DSS files are listed in Tables 6.2 and 6.3 of the preceding Chapter 6.

Program *TABLES* creates TOU file tabulations and DSS files of the time series data from the *SIM* simulation results OUT and CRM files. *TABLES* time series records allow various arithmetic manipulations of the data prior to creating DSS records in a DSS file or tabulations in a TOU file. For CRM, the *TABLES* time series tables and DSS records are limited to a maximum sequence length of 12 months for the data recorded in the CRM file, which can be any 12 months defined by CR3. The *SIM* generated SOU and DSS files impose no limit on the number of months in the CRM simulation sequences that are recorded in the output files.

TABLES generated DSS files treat the entire hydrologic period-of-analysis as a single time series record length. For example, the storage volumes tabulated in Table 8.11 are plotted as a single sequence extending from April 1940 through March 2013, without differentiating between the individual CRM simulation sequences. *SIM* generated DSS files treat each CRM simulation sequence as a separate record. Thus, the CRM simulation results can be presented as plots of the multiple individual sequences if the DSS file is created with *SIM* rather than *TABLES*. Figures 8.1 and 8.2 of Example 8.3 illustrate plotting CRM simulation results with HEC-DSSVue from data in a DSS file created with *SIM*.

Variables are defined in the preceding Chapters 5 and 6 along with the abbreviations denoting variables in the column headings of the tables in a SOU file. The same identifiers are used with the *TABLES* time series records. A SOU file contains separate simulation results tables in the format illustrated by Figure 6.4 for each control point, water right, and reservoir selected for output using the *JD* record output options and *CO*, *WO*, *GO*, and *RO* input records.

Table 8.16 of Example 8.2 illustrates the format of the tables in a SOU file. Example 8.2 has a 74-year hydrologic period-of-analysis, 30-month CRM simulation period beginning in May, and the 72 sequences defined in Table 8.2. The SOU file variables are the same and the format is almost the same for either CRM or conventional non-CRM simulations. However, for CRM simulations, sequencing information is added as the first five columns of control point tables with the default set of variables adopted in *OF* record field 5, as illustrated by Table 8.16. The sequencing indices are not included with the water right and reservoir tables in the SOU file. The five indices are defined below with values from Example 8.2 and Tables 8.2 and Table 8.16 shown in parenthesis. These same indices are written to the *SIM* message file if ICHECK option 10 is activated in *JD* record field 4 as illustrated by Table 8.31 of Example 8.5.

- Month The month index increments from 1 to the total number of months for which simulation computations are performed. (total = 74 years×12 months/year×3 cycles = 2,664 months)
- CRMM The CRM month index increments from 1 to the total number of months for which CRM computations are performed. (total = 30 months × 72 simulations = 2,160 months)
- Seq CRM simulation sequence counter. (1, 2, 3, ... , 72)
- Cycle Loop of the CRM computations. (The 3 cycles of Example 8.2 are defined in Table 8.2.)
- Mon CRM sequence month. (1 (May of first year), 2, 3, 4, ... , 29, 30 (October of third year))
- File -99 means the month is not included in a CRM simulation sequence or in the CRM and DSS files. A 0 means the month is included in one or more CRM simulation sequences and the CRM and DSS files. All months are always included in the SOU file. (In Example 8.2, the File index is 0 for 2,160 months and -99 for 504 months.)

Examples 8.2 and 8.3 Employing the Equal-Weight Approach and CR1 of 30 Months

Examples 8.2 and 8.3 illustrate the application of the equal-weight and annual cycle options for simulation sequences longer than a year. A 30-month simulation period (CR1 = 30) beginning in May (CR2 = 5) is adopted. The 30-month simulations extend from May of the first year through October of the third year. Example 8.2 employs the default cycling as specified by a blank or zero CR record field 6 (CR5 = 0). CR5 option 2 is activated for Example 8.3. The 72 simulation sequences of Example 8.2 are listed in Table 8.2. The 24 simulation sequences of Example 8.3 are listed in Table 8.3. The storage contents of each of the six reservoirs is set at 10% of capacity at the beginning of each of the 72 thirty-month simulations listed in Table 8.2 (Example 8.2) and 24 thirty-month simulations listed in Table 8.3 (Example 8.3).

The first five records of the *SIM* input DAT file are reproduced as Table 8.13. One of the four CR records is employed in each execution of *SIM* by removing the asterisks **. Examples 8.2 and 8.3 both include alternative executions of *SIM* with the last 12 months of each 30-month simulation (CR3 = 0) and with all 30 months (CR3 = -1) included in the CRM and DSS output files. All months are automatically included in the SOU file. The default (CR3 = 0 or blank field) is the same as entering 19 for CR3 specifying inclusion of months 19 through 30 in the output. The last November through October of each simulation sequence is written to the output files.

Table 8.13
First Records in the *SIM* Input DAT File for Examples 8.2 and 8.3

JD	74	1940	10	-1	-1	4
JO	2					
RO	-1					
OF	1	1	1			MAY
**CR	30	5	0	0.10		(Example 8.2)
**CR	30	5	-1	0.10		(Example 8.2)
**CR	30	5	0	0.10	2	(Example 8.3)
**CR	30	5	-1	0.10	2	(Example 8.3)

The three 1s on the optional output files *OF* record activate the CRM, SOU, and DSS files. The plots created with HEC-DSSVue from the DSS file are labeled as beginning in May as specified by the last field of the *OF* record. The format of SOU files is illustrated by Table 8.16. Plots created with HEC-DSSVue from the data records stored in the DSS file created with *SIM* are presented as Figures 8.1 and 8.2. The CRM file is read by *TABLES* with a TIN file with either a 2FRE or 2REL record. The resulting *TABLES* output TOU files are reproduced as Tables 8.14, 8.15, 8.17, and 8.18. These tables and plots represent a small sampling of the many flexible variations of options for organizing and displaying CRM results.

CRM Example 8.2 Results

Example 8.2 involves two executions of *SIM* with all input data being identical in both runs except for different values for CR3 on the CR record. The two alternative versions of the CR record are as follows.

CR	30	5	0	0.10
CR	30	5	-1	0.10

With the first *CR* record with the default CR3 of zero, the CRM and DSS files incorporate simulation results for the last 12 months of each of the seventy-two 30-month long hydrologic sequences, which are months 19 through 30 of the sequences. Since the sequences begin in May, the simulation results are for November through October, 19 through 30 months after the beginning of May. With the second *CR* record with an entry of -1 for CR3, all of the 30 months are included in the output files. The storage level in each of the reservoirs is at 10% of conservation storage capacity at the beginning of May in each of the 72 simulation sequences.

The execution of *SIM* with the last 12 months of the simulation sequences recorded in the CRM file as specified by the default CR3 is used with the following *TABLES* input 2FRE record

2FRE 6 12

to create the frequency table of Table 8.14. These frequency metrics provide estimates of the likelihood of the storage contents of the six reservoirs at the end of 30 months being at various levels conditioned upon preceding storage contents being at 10% of storage capacity.

Table 8.14
Frequency Table from *TABLES* Output TOU File for Example 8.2

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 12

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 5

Length of simulation period (CR1) = 30 months

Number of simulations and months = 72 and 864 (CR3=19)

Initial storage multiplier (CR4) = 0.100

RESERVOIR	STANDARD		PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	364445.	195493.	0.	0.	0.	0.	50699.	206222.	337144.	379450.	449054.	570240.	570240.	570240.
Whit	556985.	92997.	344743.	357486.	366161.	376715.	393342.	498702.	583462.	615749.	627100.	627100.	627100.	627100.
WacoL	173008.	32914.	41632.	63702.	72944.	97328.	128485.	170831.	184936.	188236.	192100.	192100.	192100.	192100.
Belton	257485.	170014.	0.	0.	0.	0.	18374.	88947.	184187.	281434.	353298.	455630.	457600.	457600.
George	19981.	15955.	0.	0.	0.	0.	0.	0.	12467.	23089.	32468.	36982.	37100.	37100.
Grang	36441.	27914.	0.	0.	0.	0.	0.	10045.	22746.	39453.	62028.	65500.	65500.	65500.
Total	1408345.	460854.	492888.	496169.	500111.	542173.	801532.	1018131.	1402433.	1521247.	1620138.	1880802.	1949595.	1949640.

The statistics in Table 8.14 are for storage contents at the end of October, thirty months after the preceding storage of 10% of capacity at the beginning of May. The storage frequency table is labeled month 12 which is the 12th month of the 12 months included in the CRM file. The storage contents of Belton Reservoir at the end of 30 months equals or exceeds 184,187 acre-feet during 60% of the 72 simulations. Given a storage volume of 45,760 acre-feet (10% capacity) in Belton Reservoir at the beginning of May, the estimated probability is 25 percent that the storage content 30 months later will equal or exceed 455,630 acre-feet.

Many typical CRM applications will adopt a simulation period (CR1) of 12 months or less. For simulations with CR1 greater than 12 months, the parameter CR3 on the *CR* record can be used to specify the 12 months of *SIM* simulation results that are included in the CRM file read by the routines in *TABLES* with the default (CR3=0) being the last 12 months. The 2FRE and 2FRQ frequency and 2REL reliability analysis routines in *TABLES* can be applied to either all months included in the CRM file with no limit on the number of months (CR3 = -1 if CR2 >12 months)

or to a specified month of the year if the CRM file sequences do not exceed 12 months. Most of the routines in *TABLES*, other than frequency and reliability analyses activated by 2FRE, 2FRQ, and 2REL records, are designed for a 12-month year though the 12-months can begin in any month. With CR1 greater than 12 months, these routines can be applied only if the CRM file contains results for only 12 months of the simulation sequences, For example, the time series records illustrated by Table 8.11 of Example 8.1 function with CRM only if either $CR1 \leq 12$ or $CR1 > 12$ but the entry for CR3 is not a negative one (-1).

The storage frequency metrics of the Table 8.15 illustrate the concept of probabilistic predictions of conditions at an instant in time any integer number of months into the future, which for this example is 30 months after the beginning of May. The following discussion and Table 8.16 illustrate the alternative concept of probabilistic predictions of conditions occurring during a period of any specified integer number of months, which for this example extends from the beginning of May of the first year through October of the third year.

The reliability table of Table 8.15 was developed with *TABLES* with a 2REL record and *SIM* simulation results with CR3 set at -1 to record all 30 months in the CRM file. The volume reliability is 87.74% for the 30 month simulation period for the aggregation of all diversions. 87.74% of the total diversion demand is supplied during the 72 simulations.

Table 8.15
Reliability Table from *TABLES* Output TOU File for Example 8.2

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 5
Length of simulation period (CR1) = 30 months
Number of simulations and months = 72 and 2160 (CR3=-1)
Initial storage multiplier (CR4) = 0.100

NAME	TARGET	MEAN	*RELIABILITY*		+++++ PERCENTAGE OF MONTHS +++++							----- PERCENTAGE OF SEQUENCES -----						
	DIVERSION (AC-FT/SQ)	SHORTAGE (AC-FT/SQ)	PERIOD (%)	VOLUME (%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%
PK	661959.9	55230.99	88.06	91.66	88.1	88.2	88.4	89.1	91.1	93.3	97.4	36.1	40.3	51.4	68.1	93.1	100.0	100.0
Whit	46656.0	14216.35	70.05	69.53	70.0	70.0	70.0	70.0	70.3	70.4	70.5	8.3	8.3	11.1	20.8	50.0	84.7	98.6
WacoL	209433.7	2715.85	98.01	98.70	98.0	98.0	98.0	98.0	98.3	98.6	99.1	99.6	83.3	86.1	88.9	93.1	100.0	100.0
WacoG	94380.5	10657.50	92.18	88.71	92.2	92.5	92.7	93.2	94.0	94.4	95.0	16.7	29.2	40.3	55.6	88.9	100.0	100.0
High	130905.6	19745.59	90.83	84.92	90.8	90.9	91.1	91.9	93.1	94.3	95.0	12.5	18.1	30.6	45.8	79.2	98.6	100.0
Belton	467838.1	68064.70	81.81	85.45	81.8	82.1	82.4	83.1	84.3	87.5	91.6	30.6	34.7	40.3	52.8	79.2	98.6	100.0
George	66422.0	16367.84	69.68	75.36	69.7	70.1	70.5	72.0	74.3	78.8	90.0	12.5	16.7	20.8	30.6	55.6	87.5	100.0
Grang	108931.0	17131.99	79.40	84.27	79.4	79.7	80.2	81.9	84.9	88.0	92.8	22.2	26.4	38.9	48.6	70.8	97.2	100.0
Camer	577727.7	131345.38	73.10	77.27	73.1	74.1	74.6	77.7	84.7	91.9	99.1	0.0	0.0	1.4	20.8	58.3	95.8	100.0
Bryan	268164.2	21390.22	83.56	92.02	83.6	83.7	84.3	90.6	97.9	98.9	99.4	6.9	26.4	37.5	65.3	100.0	100.0	100.0
Hemp	2945604.0	327036.88	75.79	88.90	75.8	78.4	80.6	88.3	91.4	93.8	99.4	0.0	20.8	38.9	55.6	88.9	100.0	100.0
Total	5578023.0	683903.25					87.74											

The reliability table of Table 8.15 and time series tabulations of Table 8.16 were developed from the same execution of *SIM* with CR3 set at -1 on the *CR* record to include all 30 months in the simulation results CRM file. The SOU file automatically includes all months. The format of the SOU file is illustrated by Table 8.16, which includes only a small portion of the file. Table 8.16 contains only the beginning and ending of a table for only one control point.

Table 8.16
Portion of First Table in *SIM* Simulation Output SOU File for Example 8.2

Control point identifier: PK

CRM with CR1= 30, CR2= 5, CR3= -1 and CR5= 0 results in 72 simulation sequences.

Months included in the CRM simulation have a 0 and months excluded have a -99 in the 6th column.

Month	CRMM	Seq	Cyc	Mon	File	Year	Month	NAT	REG	UNA	STO	TAR	SHT
1	0	0	1	0	-99	1940	1	10094.00	66120.23	0.00	497885.97	13893.515	0.000
2	0	0	1	0	-99	1940	2	10172.00	0.00	0.00	491928.12	15346.859	0.000
3	0	0	1	0	-99	1940	3	836.00	0.00	0.00	468528.19	17850.770	0.000
4	0	0	1	0	-99	1940	4	16772.00	0.00	0.00	461625.97	21081.352	0.000
5	1	1	1	1	0	1940	5	114403.00	0.00	0.00	146425.53	23909.152	0.000
6	2	1	1	2	0	1940	6	289797.00	6884.89	0.00	401705.62	26687.955	0.000
7	3	1	1	3	0	1940	7	45691.00	0.00	0.00	408288.31	28896.883	0.000
8	4	1	1	4	0	1940	8	242432.00	153665.66	0.00	463142.91	27139.244	0.000
9	5	1	1	5	0	1940	9	54126.00	100929.82	0.00	383605.03	24498.135	0.000
10	6	1	1	6	0	1940	10	3317.00	62834.17	0.00	297066.31	21228.352	0.000
11	7	1	1	7	0	1940	11	79433.00	0.00	0.00	359699.09	18371.150	0.000
12	8	1	1	8	0	1940	12	49363.00	0.00	0.00	393328.03	15896.641	0.000
13	9	1	1	9	0	1941	1	9910.00	0.00	0.00	387746.78	13893.515	0.000
14	10	1	1	10	0	1941	2	75951.00	0.00	0.00	450372.38	15346.859	0.000
15	11	1	1	11	0	1941	3	64391.00	0.00	0.00	494453.53	17850.770	0.000
16	12	1	1	12	0	1941	4	201160.00	104124.19	104124.19	570240.00	21081.352	0.000
17	13	1	1	13	0	1941	5	1267722.00	1244269.75	1244269.75	570240.00	23909.152	0.000
18	14	1	1	14	0	1941	6	627107.00	599129.94	599129.94	570240.00	26687.955	0.000
19	15	1	1	15	0	1941	7	140733.00	103367.27	103367.27	570240.00	28896.883	0.000

Months 20 through 2649 are omitted here.

2650	2148	72	3	18	0	2012	10	30562.50	15198.19	0.00	40556.89	21228.352	0.000
2651	2149	72	3	19	0	2012	11	0.00	21803.54	0.00	0.00	18371.150	0.000
2652	2150	72	3	20	0	2012	12	0.00	0.00	0.00	0.00	15896.641	15896.641
2653	2151	72	3	21	0	2013	1	7960.30	0.00	0.00	0.00	13893.515	5933.215
2654	2152	72	3	22	0	2013	2	12436.80	0.00	0.00	0.00	15346.859	2910.059
2655	2153	72	3	23	0	2013	3	2494.40	0.00	0.00	0.00	17850.770	15356.369
2656	2154	72	3	24	0	2013	4	5678.90	0.00	0.00	0.00	21081.352	15402.451
2657	2155	72	3	25	0	2013	5	8944.80	0.00	0.00	0.00	23909.152	14964.353
2658	2156	72	3	26	0	2013	6	18299.00	0.00	0.00	0.00	26687.955	8388.955
2659	2157	72	3	27	0	2013	7	51098.40	22201.52	0.00	0.00	28896.883	0.000
2660	2158	72	3	28	0	2013	8	35782.30	8643.06	0.00	0.00	27139.244	0.001
2661	2159	72	3	29	0	2013	9	14296.10	0.00	0.00	0.00	24498.135	10202.035
2662	2160	72	3	30	0	2013	10	19362.30	0.00	0.00	0.00	21228.352	1866.051
2663	2160	72	3	30	-99	2013	11	9707.20	0.00	0.00	0.00	18371.150	8663.949
2664	2160	72	3	30	-99	2013	12	36312.40	0.00	0.00	20433.20	15896.641	0.000

In Example 8.2, simulation computations are performed and results are recorded in the SOU file for 2,664 months.

$$\text{Total} = 74 \text{ years} \times 12 \text{ months/year} \times 3 \text{ cycles} = 2,664 \text{ months}$$

The 72 simulation sequences listed in Table 8.2 exclude 504 of the 2,664 months. The 504 months that are not included in the CRM sequences have a -99 in the 6th column of Table 8.16. Whereas the SOU tables include all 2,664 months, the CRM and DSS files include only the 2,160 months included in the 72 CRM simulation sequences, excluding the other 504 months. In order to save space in this manual, only results for the 1st through 19th months and 2,650th through 2,664th months of the simulation computations are included in Table 8.16.

A SOU file contains a separate simulation results table for each control point, water right, and reservoir specified by parameters on the *JD*, *CO*, *WO*, *GO*, and *RO* input records. Table 8.17 includes only the simulation results for control point PK.

CRM Example 8.3 Results

Examples 8.2 and 8.3 illustrate the application of the annual cycle option for simulation sequences longer than one year. The *SIM* input dataset for Example 8.3 is identical to Example 8.2 except for changing CR5 from the default option 1 (CR5 = 0 or 1) to option 2 (CR5 =2). Example 8.3 involves two executions of *SIM* with all input data being identical in both except for different values for CR5 on the *CR* record. The two alternative versions of the *CR* record adopted in Example 8.3 are as follows.

```
CR 30 5 0 0.10 2
CR 30 5 -1 0.10 2
```

Example 8.2 employs the default cycling illustrated by Table 8.2 which results in 72 simulation sequences. Individual months of the 888-month (74-year) 1940-2013 hydrology are incorporated in multiple sequences. CR5 option 2 is employed in Example 8.3 which limits use of each month of hydrology to one hydrologic simulation sequence, reducing the sequences to the 24 listed in Table 8.3. Unlike Example 8.3 with CR5=2, Example 8.2 with CR5=0 repeats the same months of hydrology in multiple simulation sequences. CR5 option 2 allows the naturalized flow and net evaporation-precipitation data provided in the FLO and EVA files to be sequentially subdivided into CRM simulation sequences without repetition or cycling. The 24 hydrology sequences in Example 8.3 are the same as the first 24 sequences in Example 8.2.

The simulation results based on 24 CRM sequences summarized in Tables 8.17 and 8.18 can be compared with the previously discussed results based on 72 sequences that are presented in Tables 8.14 and 8.15. Though similar, significant differences are observed in the simulation results based on the two alternative computational strategies applying the same hydrologic data.

Table 8.17
Frequency Table from *TABLES* Output TOU File for Example 8.3

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 12

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 5

Length of simulation period (CR1) = 30 months

Number of simulations and months = 24 and 288 (CR3=19)

Initial storage multiplier (CR4) = 0.100

RESERVOIR	STANDARD		PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	355211.	199179.	0.	0.	0.	13881.	94398.	251672.	292972.	345544.	493105.	570240.	570240.	570240.
Whit	570349.	96575.	344743.	348990.	353238.	367121.	393803.	581306.	619581.	627100.	627100.	627100.	627100.	627100.
WacoL	172330.	30827.	72285.	81722.	91158.	117496.	142699.	159674.	185381.	188236.	191278.	192100.	192100.	192100.
Belton	257485.	193296.	0.	0.	0.	0.	3728.	75483.	171754.	312070.	441323.	457600.	457600.	457600.
George	19319.	17322.	0.	0.	0.	0.	0.	0.	10207.	28279.	35789.	37100.	37100.	37100.
Grang	33555.	28676.	0.	0.	0.	0.	0.	10045.	13375.	38061.	59772.	65500.	65500.	65500.
Total	1408249.	498881.	497445.	498899.	500353.	565477.	822890.	999005.	1278443.	1581798.	1665801.	1941669.	1949640.	1949640.

Table 8.18
Reliability Table from TABLES Output TOU File for Example 8.3

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option

Annual cycles starting in month 5

Length of simulation period (CR1) = 30 months

Number of simulations and months = 24 and 720 (CR3=-1)

Initial storage multiplier (CR4) = 0.100

NAME	TARGET	MEAN	*RELIABILITY*		+++++++ PERCENTAGE OF MONTHS ++++++								----- PERCENTAGE OF SEQUENCES -----						
	DIVERSION (AC-FT/SQ)	SHORTAGE (AC-FT/SQ)	PERIOD (%)	VOLUME (%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%	
PK	661959.8	48487.05	90.28	92.68	90.3	90.6	90.6	90.8	91.5	93.6	98.5	33.3	37.5	54.2	66.7	100.0	100.0	100.0	
Whit	46656.0	14646.52	69.58	68.61	69.6	69.6	69.6	69.9	69.9	69.9	70.1	0.0	0.0	0.0	8.3	45.8	91.7	95.8	
WacoL	209433.6	405.58	99.72	99.81	99.7	99.7	99.7	99.9	99.9	99.9	99.9	95.8	100.0	100.0	100.0	100.0	100.0	100.0	
WacoG	94380.6	9603.10	92.78	89.83	92.8	93.2	93.3	93.7	94.7	95.1	95.4	12.5	25.0	37.5	62.5	95.8	100.0	100.0	
High	130905.6	18933.39	90.97	85.54	91.0	91.1	91.1	91.9	93.2	94.6	95.6	8.3	16.7	29.2	45.8	79.2	95.8	100.0	
Belton	467838.0	55999.09	84.72	88.03	84.7	85.1	85.4	86.1	86.8	89.7	94.0	25.0	29.2	37.5	54.2	87.5	100.0	100.0	
George	66421.9	15109.45	72.22	77.25	72.2	72.4	72.8	74.6	76.8	79.9	90.8	12.5	16.7	20.8	33.3	62.5	87.5	100.0	
Grang	108930.9	15943.88	81.11	85.36	81.1	81.4	81.8	83.6	86.2	88.8	93.2	16.7	16.7	41.7	45.8	75.0	100.0	100.0	
Camer	577727.3	125324.44	74.31	78.31	74.3	75.4	75.8	79.3	85.7	92.9	99.4	0.0	0.0	0.0	16.7	62.5	95.8	100.0	
Bryan	268164.3	20046.45	84.58	92.52	84.6	84.6	85.1	91.1	98.2	99.2	99.4	4.2	16.7	33.3	66.7	100.0	100.0	100.0	
Hemp	2945605.0	283735.66	77.78	90.37	77.8	79.9	82.2	89.9	93.1	95.1	99.9	0.0	12.5	33.3	58.3	100.0	100.0	100.0	
Total	5578023.0	608234.56	89.10																

Figures 8.1 and 8.2 illustrate the format of plots created with HEC-DSSVue from data read from a DSS file created with SIM. Naturalized flow volumes in acre-feet/month at the river system outlet at control point Hemp for the 24 thirty-month simulations are plotted in Figure 8.1. The end-of-month storage volume of Belton Reservoir in acre-feet is presented in Figure 8.2 for the 24 thirty-month simulations. The storage volume of Belton Reservoir is 45,760 acre-feet (10% of capacity) at the beginning of May. The 30 end-of-month storage volumes extend from the end-of-May of the first year to the end-of-October of the third year.

SOU and DSS files can include up to 16, 12, and 11 variables (such as naturalized flow or storage volume) for each of the control points, reservoirs, and water rights, respectively, selected for inclusion in the DSS file. With CRM, A DSS record stored in a DSS file consists of simulation results data for a single CRM simulation sequence for one particular variable for a particular either control point, water right, or reservoir. Thus, numerous DSS records can be generated by a single execution of the SIM simulation model. HEC-DSSVue and the HEC data storage system (DSS) provides flexible convenient capabilities for managing very large time series data sets. HEC-DSSVue includes a variety of features for performing various data manipulations, arithmetic operations, statistical analyses, and creating time series graphs.

The legend labels Figures 8.1 and 8.2 include DSS pathname part F automatically assigned as CRM01CP, CRM02CP, ... , CRM24CP. The sequence numbers 1, 2, ... , 23, 24 are also included in the sequencing index columns of the default control point tables in the SOU file.

TABLES also creates DSS files from CRM or OUT files. However, CRM sequences must be limited, using CR3 options if necessary, to lengths not exceeding 12 months, and the DSS records are single 1940-2013 time series rather than individual records for each CRM sequence.

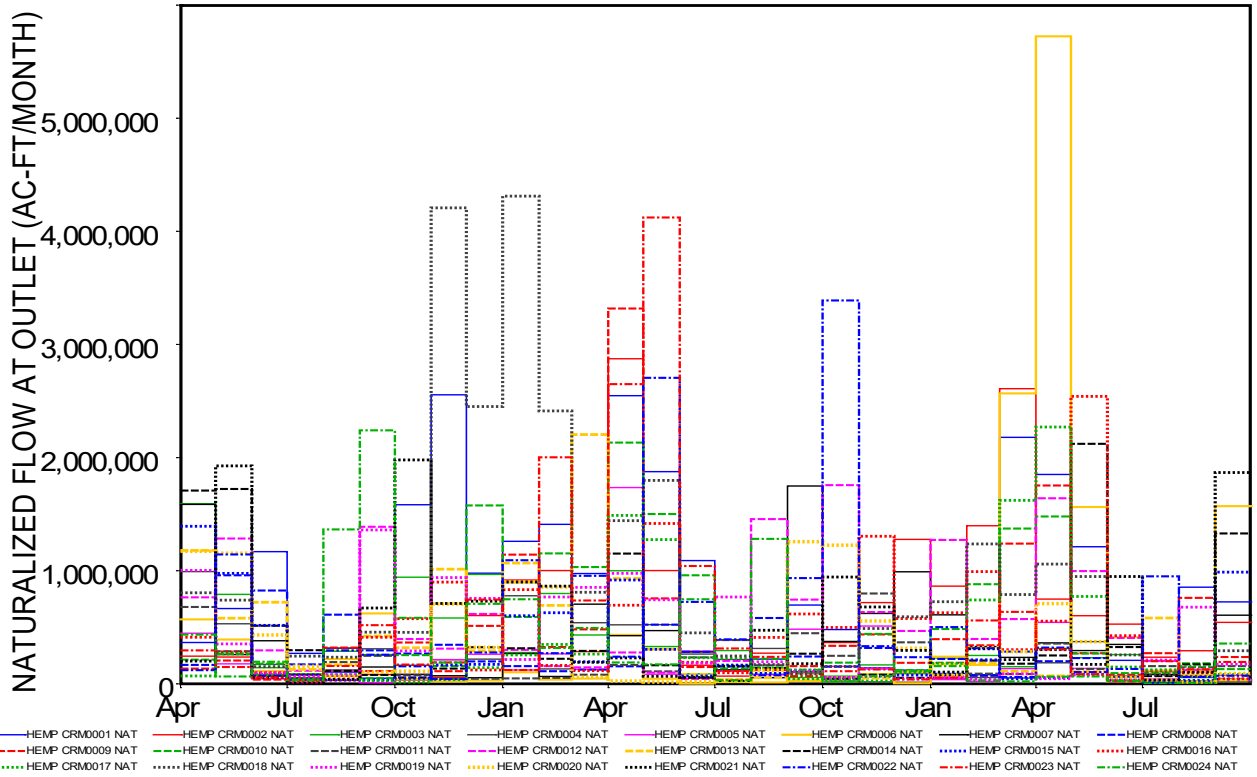


Figure 8.1 Naturalized Flow at Control Point Hemp with the Twenty-Four 30-Month Sequences

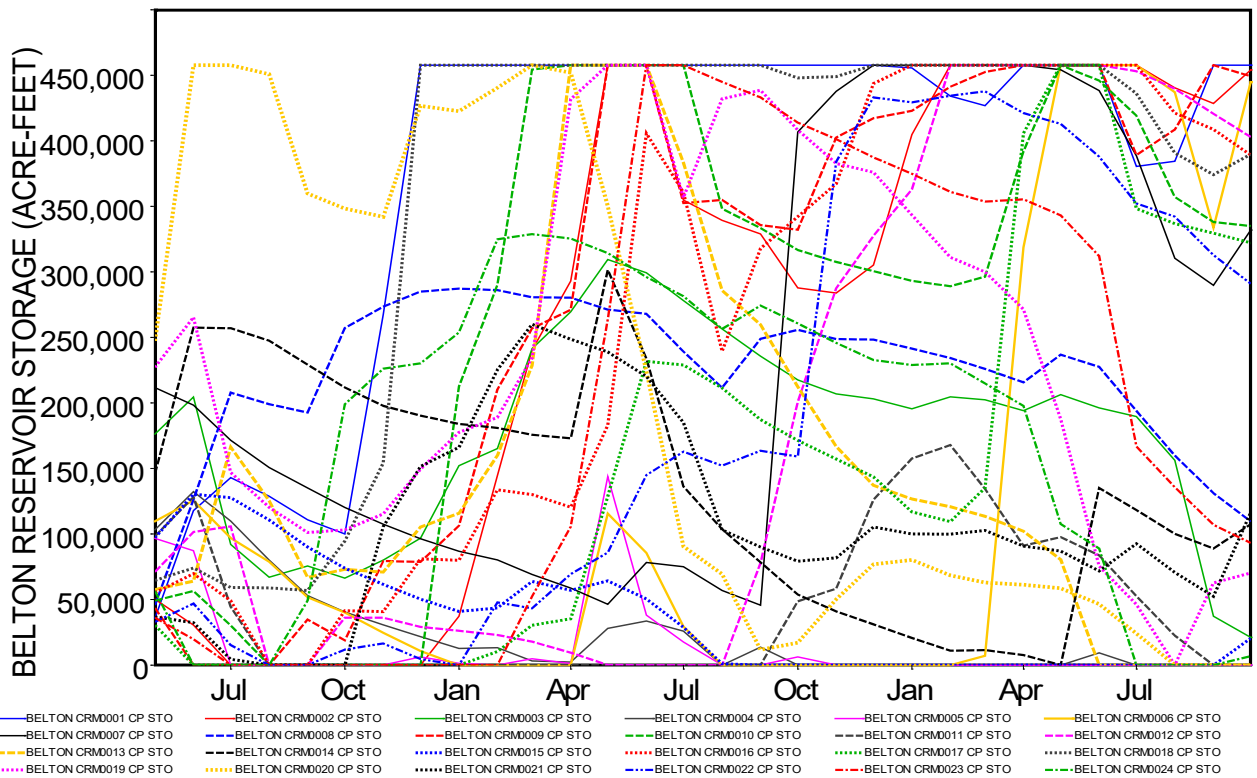


Figure 8.2 End-of-Month Storage Contents of Belton Reservoir with the 24 Sequences

Options for Assigning Probabilities to the Simulation Sequences

Two alternative strategies may be adopted for assigning probabilities to each of the short-term hydrologic simulation sequences.

equal-weight option – Frequencies and reliabilities are estimated based on simply treating each simulation sequence as one possibility out of the total number of simulation sequences. Preceding storage is not explicitly considered in assigning probabilities to sequences.

probability array option – Preceding storage content or preceding changes in storage content are considered in assigning probabilities to each of the individual simulation sequences using techniques outlined by the remainder of this chapter.

The preceding example illustrates the default equal-weight approach. The 73 alternative simulations are each weighted the same in the frequency and reliability computations. Each of the 73 twelve-month long sequences of naturalized flows and net evaporation rates represent one possible occurrence of hydrologic conditions. Each sequence is implicitly assigned a weight of 1/73 in the frequency and reliability counts. Some sequences have extremely low or extremely high flow volumes and net evaporation rates, representing infrequent drought or flooding conditions, while other sequences reflect more normal hydrologic conditions. Relatively few of the hydrologic sequences reflect infrequent extremes. Many more sequences are representative of more normal conditions that occur the majority of the time. The probabilistic nature of river basin hydrology is captured by the frequency of occurrence of the range from low to high natural stream flows and net reservoir evaporation less precipitation rates. The 73 hydrologic simulation sequences provide a sample of 73 occurrences which are adopted as being representative of the frequency characteristics of the continually varying hydrologic conditions in the river basin.

In the preceding examples, the hydrology represented by each sequence is not treated as being equally likely, but the sequences are equally-weighted in the sense of each being counted once. The CRM approach of simply applying Eqs. 8.2–8.7 with each of the N simulation sequences considered one time is called the *equal-weight option*. In the *probability array option* outlined by the remainder of this section, each sequence is explicitly assigned both an exceedance probability and incremental probability that vary between sequences. The summation of the incremental probabilities total to 1.0.

The computational procedures activated by the *TABLES 2REL*, *2FRE*, *2FRQ*, and *2RES* records provide reliability and frequency estimates based on Eqs. 8.2, 8.3, and 8.4. The *2FRE* record options for applying the normal or log-normal probability distributions may be applied with conventional applications or with either the CRM equal-weight or probability array options. The equal-weight option provides valid estimates of frequencies and reliabilities and may often be the best choice for particular CRM applications. However, improvements in accuracy of the frequency and reliability estimates may be achieved in some applications by selected sets of other *TABLES* options that are based on more sophisticated computational methods for assigning probabilities to each of the multiple simulation sequences. These more complex options are based largely on the concept that the likelihood of the hydrologic sequences may be correlated to various degrees with changes in preceding reservoir storage levels or with storage levels.

The remainder of this chapter outlines sets of computational options incorporated in *TABLES* for assigning probabilities to each of the multiple hydrologic sequences. The *SIM* CRM simulation is not affected by these methods for assigning probabilities to the *SIM* generated simulation sequences. Likewise, the general format of the tables in the TOU file generated by *TABLES* is not affected.

Alternative Probability Estimation Strategies

Reliability and frequency estimates vary depending on the approach adopted in *TABLES* for assigning probabilities to each of the multiple hydrologic sequences of naturalized flows and net evaporation-precipitation depths generated by the *SIM/SIMD* simulation. *TABLES* provides alternative options for various tasks associated with assigning probabilities to each of the multiple CRM simulation sequences. The alternative strategies are outlined as follows.

1. The *equal-weight option* is based on weighting each of the hydrologic sequences the same in applying the basic relative frequency concepts expressed in Equations 8.2, 8.3, 8.4, 8.5, 8.6, and 8.7.
2. The *probability array option* allows probabilities to be assigned to each hydrologic sequence with alternative sets of methods reflecting various factors including hydrologic persistence. A key consideration is relating naturalized flow volume to increases or decreases in reservoir storage contents during the preceding month or any specified number of preceding months or the total preceding storage contents.
 - a. The *flow-frequency (FF) relationship option* is based on assigning exceedance probabilities directly to naturalized flow volumes using either the log-normal probability distribution or Weibull formula. Preceding reservoir storage may be either ignored or incorporated into the determination of probability distribution parameters by using only sequences with preceding storage falling within a specified range.
 - b. The *storage-flow-frequency (SFF) relationship option* is based on probabilistically representing deviations in naturalized flow volumes from the amounts indicated by a regression relationship between naturalized stream flow volume and either preceding reservoir storage volume or change in preceding storage volume.

The equal-weight option involves no special features in *TABLES*. The computations associated with the *2REL*, *2FRE*, *2FRQ*, and *2RES* records and Eqs. 8.2–8.7 are the same for a conditional reliability modeling (CRM) application with the equal-weight option and a conventional non-CRM application. The *2FRE* record also includes an option that allows use of a probability distribution function for use with either CRM or non-CRM applications. This generic *2FRE* record probability distribution option is separate from the CRM probability array option described below and may be applied in combination with the CRM equal-weight option.

The probability array option also uses the same computational routines associated with the *2REL*, *2FRE*, *2FRQ*, and *2RES* input records but incorporates an exceedance probability (FF or SFF) relationship used to assign an incremental probability to each simulation sequence. These

incremental probabilities vary between sequences and sum to 1.0. If the incremental probability (IP) array happens to contain equal probabilities for all sequences, the probability array and equal-weight options yield the same reliability and frequency analysis results.

The basic concept of applying the probability array methodology using a SFF relationship is to attempt to improve the accuracy of frequency and reliability estimates by assigning probabilities to each of the multiple simulation sequences based on reservoir storage or changes in reservoir storage occurring prior to the period of analysis. A significant decrease in reservoir storage during the preceding month or several months indicates dry hydrologic conditions. Hydrologic persistence would mean a higher likelihood of low flows over the next several months. Likewise, increases in storage levels indicate wetter preceding conditions that would indicate a higher likelihood of higher flows over the next several months. The probability array methodology includes a variety of options for performing various computational tasks.

The CRM probability array option assigns probabilities to each of the hydrologic sequences. Either a flow-frequency (FF) or storage-flow-frequency (SFF) relationship is developed for use in developing the incremental probability (IP) array. The SFF relationship option incorporates preceding reservoir storage and changes in preceding storage in more detail in assigning of flow probabilities. With the probability distribution option for performing CRM reliability and frequency analyses, an array assigning a probability to each of the hydrologic sequences produced in the *SIM/SIMD* simulation is developed by *TABLES* in two steps.

1. A FF or SFF relationship is developed from sequences of monthly naturalized flow volume and preceding storage volume read from a *SIM/SIMD* output file for a conventional single long-term *SIM/SIMD* simulation as specified by a *5CRI* record.
2. The array of naturalized flow volumes for each simulation sequence read from a CRM execution of *SIM/SIMD* for a given initial storage condition is combined with the FF/SFF relationship of step 1 above to develop an array of incremental probabilities (IP array) for the hydrologic sequences as specified by a *5CR2* record.

The *5CRI* record controls development of a flow-frequency (FF) or storage-flow-frequency (SFF) relationship from a single conventional long-term *SIM/SIMD* simulation using either annual or monthly (non-annual) cycles to define flow segments. The *5CR2* record develops an array assigning an incremental probability (IP) to each simulation sequence of a CRM analysis. The FF or SFF relationship developed by the *5CRI* record is used in the routines controlled by the *5CR2* record to develop the incremental probability (IP) array.

The model-user may specify lower and upper limits defining a reservoir storage range on the *5CRI* record. Only those naturalized flow sequences with the preceding storage falling within the specified range are used in building the FF or SFF relationship. For example, assume that a CRM analysis is being performed for an initial storage content of 50 percent of the storage capacity. The model-user may choose to build the FF or SFF relationship using only flow sequences that follow storage contents falling in the range of 20 to 80 percent of capacity. For the FF option, the storage limits provide the only mechanism for relating naturalized flow volume to preceding storage. The FF option may also be applied without specifying storage limits and thus without relating naturalized flow volume to preceding storage.

Relationship between Naturalized Stream Flow and Preceding Reservoir Storage Change

The storage-flow-frequency (SFF) option consists of assigning probabilities to each of the multiple simulation sequences as a function of either (1) preceding reservoir storage volume or (2) changes in reservoir storage volume during any specified number of preceding months. Since the CRM simulations are conditioned on preceding reservoir storage with all of the equal-weight or probability array computational strategies, relating future naturalized flow volume to preceding cumulative total storage volume in developing the SSF relationship is convenient. However, naturalized flow volumes are likely to be more closely correlated to changes in storage volume during one or more preceding months. Thus preceding change in storage volume (rather than storage volume) may better capture hydrologic persistence in employing a SFF relationship.

The computational strategy for the SFF option pivots around the storage-flow-frequency (SFF) relationship, which relates exceedance probabilities to the random variable $Q_{\%}$.

$$Q_{\%} = \frac{Q}{Q_S} 100\% \quad (8.8)$$

where Q is the naturalized flow volume over one or more months observed in the *SIM/SIMD* CRM simulation results, and Q_S is the corresponding expected value of the naturalized flow volume determined from a regression equation reflecting preceding storage volume or changes in storage volume over a specified number of preceding months. The naturalized flow volume Q is the total volume summed for the months specified by the parameter *FM* on the *5CR1* record which defaults to the *CR1* months from the *CR* record. The flow $Q_{\%}$ is the naturalized flow volume observed in the model as a percentage of the flow volume Q_S expected from relating flow to preceding storage or change in storage. The magnitude of $Q_{\%}$ expresses the deviation of the flow volume from the expected value of the flow volume conditioned on preceding storage conditions as modeled by a regression equation.

Q_S represents a best-estimate prediction of future flow given preceding hydrologic conditions, primarily as reflected in changes in reservoir storage contents. However, the predicted or expected value of the flow (Q_S) can optionally be adjusted to reflect other factors considered external to the simulation model such as climatic teleconnection patterns.

Regression Methods

The following exponential (Eq. 8.9), power (Eq. 8.10), linear (Eq. 8.11), and combined (Eq. 8.12) forms of regression equations may be used to relate the naturalized flow volume Q_S in Eq. 8.8 to the preceding storage volume or change in storage volume S specified on the *5CR2* record. Eq. 8.9 is the default option, where e is the base of the natural logarithms.

$$Q_S = a \times e^{S/b} \quad (8.9)$$

$$Q_S = bS^c \quad (8.10)$$

$$Q_S = a + bS \quad (8.11)$$

$$Q_S = a + bS^c \quad (8.12)$$

The parameters a, b, and c are determined by applying least-squares regression to the naturalized flow volumes and preceding reservoir storage or change in storage volumes from a long-term *SIM* simulation. An option allows forcing the y-intercept to be zero (a=0) for Eqs. 8.11 and 8.12. If the coefficient c is 1.0, Eq. 8.12 reduces to Eq. 8.11. With a value for c other than 1 and a coefficient a of zero, Eq. 8.12 reduces to Eq. 8.10.

An 888-month 1940-2013 simulation comparing a 3-month naturalized flow volume to the preceding storage volume or change in storage volume will have either 73 or 74 (annual option) or 886 (monthly option) pairs of values of S_i and Q_i . The storage S_i is the volume content or change thereof of one or more specified reservoirs preceding each 3-month sequence. The flow Q_i is the total volume of the naturalized stream flow at one or more control points over each 3-month sequence. Application of regression analysis to the pairs of S_i and Q_i results in the parameters a, b, and c for the alternative Eqs. 8.9, 8.10, 8.11, or 8.12. The calibrated regression model is applied with the storage or storage change volume specified on the 5CR2 record.

Standard least-squares linear regression methods outlined in statistics and numerical methods textbooks are used.

$$E(Y|x) = a + bx \quad (8.13)$$

$$b = \frac{n \sum x_i y_i - (\sum x_i)(\sum y_i)}{n \sum x_i^2 - (\sum x_i)^2} \quad (8.14)$$

$$a = \bar{y} - b \bar{x} \quad (8.15)$$

$E(Y|x)$ denotes the conditional expectation of Y given x, and \bar{y} and \bar{x} are the means of y and x. Eqs. 8.13, 8.14, and 8.15 are applied with $x = S$ and $y = Q$ to determine values for the coefficients a and b in Eq. 8.11, which represent the y-intercept and slope of a straight line plot.

The linear regression equations (Eqs. 8.13–8.15) are applied to transformed variables to obtain the coefficients a, b, and c for Eq. 8.9 and Eq. 8.10. For the exponential model of Eq. 8.9, the natural logarithm of Q is regressed with S, resulting in the y-intercept and slope of a straight line plot being represented by $\ln a$ and b, respectively. For the power function of Eq. 8.10, the logarithm of Q is regressed with $\log S$, with the resulting y-intercept and slope of a straight line plot being represented by $\log b$ and c, respectively. The coefficients b and c for Eq. 8.12 are set in two steps. The exponent c in Eq. 8.12 is fixed based on the power function regression, and then S^c and Q are regressed to obtain the coefficients a and b.

Correlation Coefficients

The correlation coefficient r is the square root of the coefficient of determination r^2 .

$$r = \sqrt{r^2} \quad (8.16)$$

The standard linear correlation coefficient r is computed as Eq. 8.17.

$$r = \frac{n \sum x_i y_i - (\sum x_i)(\sum y_i)}{\sqrt{n \sum x_i^2 - (\sum x_i)^2} \sqrt{n \sum y_i^2 - (\sum y_i)^2}} \quad (8.17)$$

The linear correlation coefficient is an index of the goodness-of-fit of the regression relationships. The *5CRI* record results in computation of the regression coefficient r from Eq. 8.17 along with the regression coefficients a , b , c of Equations. 8.9–8.15 for the selected regression equation. While Eq. 8.11 is based on a linear relationship between S and Q_s , Eqs. 8.9, 8.10, and 8.12 are based on a linear relationship between variables that are nonlinear functions of S and Q_s . The linear correlation coefficient of Eq. 8.17 is an index of the linear correlation between the previously noted transformed variables.

5CRI record field 15 activates an option to write a table of statistics to the TOU file that includes the regression and correlation coefficients. The *5COR* record creates the same table without the coefficients for the regression analysis. The *5COR* record allows correlation analyses of storage versus naturalized flow volumes to be performed without activating the other features of the *5CRI* record. The same correlation analysis is included as a *5CRI* record option.

The Spearman rank correlation coefficient for storage versus flow volume is included in the *5COR* and *5CRI* record statistics table as supplemental information. The rank correlation coefficient does not depend upon the actual values of x and y (Q_s and S) but rather their relative rank. The ranks of the two variables in the paired data set are correlated rather than the actual magnitudes. For a set of paired data, (x_i, y_i) , $i = 1, 2, \dots, n$, the x_i and y_i are ranked separately with the highest value having rank 1 and the lowest value rank n . The ranks are correlated with Eq. 8.17, which may be algebraically converted to Eq. 8.18. In correlating ranks, the rank correlation coefficient r_r is expressed as Eq. 8.18 where d_i is the difference between the ranks assigned to x_i and y_i for each of the n pairs of values.

$$r_r = \frac{6 \sum d_i^2}{n(n^2 - 1)} \quad (8.18)$$

The correlation coefficient r provides a measure of the degree of linear correlation between the variables x and y . The rank correlation coefficient r_r provides a measure of the degree of linear correlation between the ranks of the variables x and y . Values of the correlation coefficient can range between -1.0 and 1.0 .

$$-1.0 \leq r \leq 1.0 \quad \text{and} \quad -1.0 \leq r_r \leq 1.0$$

A value for r of 1.0 indicates a perfect linear correlation. A plot of x versus y would be a perfect straight line, increasing with increasing magnitudes of x and y . A value for r of -1.0 indicates that x and y are inversely correlated with y decreasing with increasing x . A value for r of 0.0 indicates no linear correlation between x and y . With r near zero, a plot of x versus y would show either random scatter or a highly nonlinear relationship.

The *5COR* correlation coefficient record may be used to compute the correlation coefficient of the sum of naturalized flows at specified control points and reservoir storage at specified reservoirs or control points, without actually developing the *5CRI* record *SFF* or *FF* relationship. The *5COR* record is designed primarily as an aid in determining whether the correlation of flow volume to preceding storage is strong enough to warrant adoption of the storage-flow-frequency (*SFF*) option and in selection of the control points and reservoirs to be used in developing *SFF* relationships. A graphical comparison external to WRAP will typically be combined with the correlation coefficients.

Probability Distributions

The exceedance probability is the estimated probability of equaling or exceeding particular values of the random variable X . Restating in terms of frequency, the exceedance frequency is the relative frequency of equaling or exceeding particular values of X . In developing a FF relation, the random variable X is the naturalized flow volume for a specified length of time. In developing a SFF relation, the random variable X is the $Q\%$ defined by Eq. 8.8. The naturalized flow volumes are the sum of the monthly amounts during the period of months specified by the parameter FM on the *5CRI* record which is equivalent to CR1 on the *CR* record. The *TABLES 5CRI* record activates two alternative options for computing exceedance probabilities that are based on either the log-normal probability distribution or Weibull formula.

The first option for modeling the probability distribution of X representing either naturalized flow volumes for a FF relationship or $Q\%$ for a SFF relationship is to apply the log-normal probability distribution using Eq. 8.19 with z derived from the normal distribution.

$$\log X = \overline{\log X} + z S_{\log X} \quad (8.19)$$

The mean $\overline{\log X}$ and standard deviation $S_{\log X}$ of the logarithms of X are computed. The frequency factor z is entered by linear interpolation into a normal probability table built into *TABLES* to obtain cumulative probability (1-P) which is converted to exceedance probability (P).

Naturalized stream flow ranges upward from a lower limit of zero, with no defined upper limit. Likewise, the Eq. 8.8 ratio $Q\%$, representing deviations, has a lower limit of zero and no upper limit. The log-normal models the skewed distribution for these types of random variables.

The other option for assigning exceedance probabilities for a SFF or FF relationship involves ranking the flow (Q or $Q\%$) series and applying the Weibull formula:

$$P = \frac{m}{N+1} \quad (8.20)$$

where P denotes exceedance probability, m is the rank of the values ($m = 1, 2, 3, \dots, N$), and N is the total number of sample values of the random variable. The flow sequence with the greatest flow ratio $Q\%$ or flow volume is assigned a rank of 1, and the smallest is assigned a rank of N . The Weibull relative frequency formula weights each flow sequence (and associated flow volume or Eq. 8.8 flow percentage $Q\%$) equally in developing the SFF or FF relationship. The algorithm in *TABLES* extends the SFF or FF relationship by assigning an exceedance probability of 1.0 to a flow of zero. If a flow volume in a *5CR2* record application exceeds the highest flow included in the *5CRI* record FF or SFF array, the relation is linearly extrapolated using the highest two flows, subject to the limiting restriction that the probability can not be less than zero.

The probability option with a FF relationship developed using the Weibull formula is conceptually similar to the equal-weight option. The computational algorithms differ. The Weibull formula (Eq. 8.20) is applied explicitly to flow volumes at one or more specified control points. Eq. 8.20 can be compared with Eqs. 8.2 and 8.4 upon which the equal-weight option is based. In either case, the concept of relative frequency is applied with each of N sample hydrologic sequences treated as being equally-weighted. Each simulation is assigned the same incremental

probability. Relatively few sequences reflect infrequent extremely wet or dry conditions. A larger number of sequences reflect more normal flow conditions that are expected to occur more often. Thus, the computational methods model the probability distribution of stream flow volumes representing hydrologic conditions.

The accuracy of probability estimates based on direct application of relative frequency concepts reflected in Eqs. 8.2, 8.4, and 8.20 is limited by the sample size set by the number of hydrologic sequences. The log-normal probability distribution may improve modeling accuracy by providing a general form for the probability distribution considered representative of either stream flow volumes or the Eq. 8.8 flow $Q_{\%}$ as a percentage of predicted Q representing deviations from the flow volumes indicated by regression with preceding storage.

Flow-Frequency (FF) and Storage-Flow-Frequency (SFF) Relationships

The sole purpose of a *TABLES 5CRI* record is to develop either a FF or SFF relationship for use later by a *5CR2* record.

- A flow-frequency (FF) relationship is between naturalized flow volume over a specified number of months versus exceedance probability developed based on either the log-normal probability distribution or Weibull frequency formula.
- A storage-flow-frequency (SFF) relationship is between the flow ratio $Q_{\%}$ defined by Eq. 8.8 versus exceedance probability developed based on either the log-normal probability distribution or Weibull frequency formula.

The SFF relationship is developed by assigning exceedance probabilities to values of the flow ratio $Q_{\%}$ defined by Eq. 8.8 and either Eq. 8.9, 8.10, 8.11, or 8.12. Exceedance probabilities are assigned to the naturalized flow sequences as an expression of the relative likelihood of departures of flow volumes from those expected based on relating flow to preceding storage or storage change. The basic premise of the SFF option is that naturalized stream flows are correlated to some extent with either preceding storage content or changes in preceding storage content over one or more months. Significantly decreasing storage contents imply dry conditions during preceding months with a high likelihood of continued low naturalized flows. Increases in reservoir storage imply high precipitation and streamflow inflow during the preceding months with an increased likelihood of continued high flows during subsequent months. Naturalized stream flows are assumed to exhibit some degree of autocorrelation. The likelihood of flows being high during a particular time period is greater if the flows were high in preceding months. Reservoir storage contents are dependent upon stream inflows in preceding months.

The *5CRI* record routines develop either a FF or SFF relationship. Pairs of flow and storage or storage change volumes are obtained from the results of a long-term *SIM* simulation. The flow volumes are for naturalized stream flow over a specified number of months at one or more control points. The storage volumes are the storage contents of one or more reservoirs at the beginning of the period over which the naturalized flows occur. Either annual or monthly cycle options may be adopted to define the flow sequences.

Storage limits may be specified on the *5CRI* record such that the only flow sequences considered in developing the SFF or FF array are those with preceding storage falling within the

specified range. For example, if lower and upper storage volume limits equal to 25% and 90% of reservoir storage capacity are defined on the *5CRI* record, the set of flow sequences included in the FF and SFF relationship computations include only those flow sequences with preceding storage volume within the range of 25% to 90% of the reservoir capacity.

A flow-frequency (FF) array is based on applying the log-normal probability distribution or Weibull probability formula directly to the naturalized flow volumes. The array assigns exceedance probabilities to flows without considering preceding storage other than through the option that limits the flow sequences included in the computations to a specified storage range.

A storage-flow-frequency (SFF) relationship relates exceedance probability to a flow ratio expressing the deviation of flow volume from that is expected based on a given preceding storage conditions. The *TABLES 5CRI* record routines perform the following tasks resulting in production of the SFF array.

1. The main *SIM/SIMD* output file with filename extension OUT resulting from a conventional single long-term simulation is read by *TABLES* to obtain the preceding storage or change in storage and naturalized flow for each simulation sequence.
2. The preceding storage or storage change at specified control points or for specified reservoirs is summed for each simulation sequence to obtain the total storage amounts used in the analysis. Likewise, naturalized flows during specified months at specified control points are summed to obtain the total flow amounts adopted.
3. Regression analyses are performed to relate flow volume to preceding storage volume in the form of either Eq. 8.9, Eq. 8.10, Eq. 8.11, or Eq. 8.12.
4. The expected value of flow conditioned on storage is computed for each simulation sequence using the regression equation derived from step 3 above. The corresponding values of the flow $Q\%$ in percent are determined with Eq. 8.8.
5. The storage-flow-frequency (SFF) relationship is developed by connecting exceedance frequencies to $Q\%$ using either Eq. 8.19 or Eq. 8.20. The mean and standard deviation of the logarithms of $Q\%$ are computed as the parameters for the log-normal distribution option. Alternatively, an array of $Q\%$ versus exceedance probability is developed using the Weibull formula.

The product of this process activated by a *TABLES 5CRI* record is a SFF relationship connecting exceedance probabilities to values of the flow ratio $Q\%$. The SFF relationship is input to the *TABLES* routine outlined next, which is activated by the *5CR2* record to assign probabilities to each simulation sequence in a conditional reliability modeling application.

Incremental Probability (IP) Array for the CRM Simulation Sequences

After the FF or SFF relationship has been established by the *5CRI* record based on the results from a single long-term *SIM/SIMD* simulation, the next task is for the *5CR2* record to develop the IP array by assigning incremental probabilities to each of the multiple simulation sequences of a CRM execution of *SIM/SIMD*. Whereas the *5CRI* record FF and SFF relationships connect the random variable (flow volume or Equation 8.8 flow ratio $Q\%$) to exceedance

probabilities, the *5CR2* record computes incremental probabilities for these variables that are assigned to the corresponding hydrologic simulation sequences. The incremental probabilities for all simulation sequences sum to 1.0.

The flow-frequency (FF) option is based on assigning frequencies to naturalized flow sequences without considering reservoir storage contents. With the FF option, *TABLES* assigns probabilities to each of the simulation sequences as follows.

1. The main *SIM/SIMD* output file, with filename extension CRM, resulting from a CRM simulation is read by *TABLES* to obtain the naturalized flow in each month for each simulation sequence.
2. Naturalized flow volumes during specified months at specified control points are summed to obtain the total flow amounts used in the analysis.
3. The naturalized flow volume for each hydrologic sequence is combined with the previously established FF relationship to obtain an exceedance probability for each CRM hydrologic simulation sequence. Linear interpolation is used to obtain exceedance probabilities from either the normal probability table using the FF log-normal probability distribution parameters or the FF Weibull probability array.
4. The exceedance probabilities are ranked in order and converted to incremental probabilities. The incremental probability for each flow sequence is computed based on the half-way points between exceedance probabilities of the next larger and next smaller flow volumes. The incremental probability is the difference between the two exceedance probabilities.

The storage-flow-frequency (SFF) option considers either preceding storage contents or preceding storage changes in assigning probabilities to the simulation sequences. With the SFF option, *TABLES* assigns probabilities to each of the simulation sequences as follows.

1. The main *SIM/SIMD* output file (filename root.CRM) resulting from a CRM run is read by *TABLES* to obtain the naturalized flow in each month for each simulation sequence.
2. The preceding storage or change in storage for the pertinent reservoirs or control points is read from either a *5CR2* record or *SIM/SIMD* beginning reservoir storage (BRS) file.
3. The preceding storages or storage changes at specified reservoirs or control points are summed for each simulation sequence to obtain the total storage amounts used in the analysis. Likewise, naturalized flows during specified months at the specified control points are summed to obtain the total flow amounts used in the analysis.
4. The expected value of flow conditioned on preceding storage quantity is computed for each simulation sequence using either Eq. 8.9, Eq. 8.10, Eq. 8.11, or Eq. 8.12. The corresponding values of the flow ratio $Q\%$ are determined with Eq. 8.8.
5. The value of $Q\%$ for each hydrologic sequence is combined with the previously established SFF relationship using linear interpolation to obtain an exceedance probability for each CRM hydrologic simulation sequence.

6. The exceedance probabilities are ranked in order and converted to incremental probabilities. The incremental probability for each Q% is computed based on the half-way points between the exceedance probabilities of the next larger Q% and next smaller Q%. The incremental probability is the difference between the two exceedance probabilities.

The product of this process activated by a *TABLES 5CR2* record is an incremental probability (IP) array assigning incremental probabilities to each of the simulation sequences included in the *SIM/SIMD* CRM results. The IP array is used in the reliability and frequency routines activated by *2REL*, *2FRE*, *2FRQ*, and *2RES* records.

Incorporation of Other Factors Such as Climate Cycle Teleconnections

The optional parameter QX entered in *5CR2* record field 15 is designed to allow factors other than preceding reservoir storage or preceding storage change to be incorporated in the development of the SFF and incremental probability IP arrays. Q_s determined with equation 8.9, 8.10, 8.11, or 8.12 or by setting Q_s equal to the long-term mean is multiplied by the multiplier factor QX, which has a default of 1.0. QX is determined external to the WRAP modeling system and provided as input to the *TABLES* CRM computations as a parameter on the *5CR2* record.

In the development of the SSF array, one of the alternative regression equations 8.9–8.12, is selected to compute Q_s for use in Eq. 8.8 in assigning Q% for each hydrologic simulation sequence. The Q_s computed with the regression equation represents the expected value or long-term average of the naturalized stream flow volume for a given preceding change in storage. Q_s can also be set at the mean without regard to storage. The multiplier factor QX allows Q_s to be adjusted to deviate from the expected value of Q. For example, with CR1 of six months, if based on information regarding climatic cycles, the stream flow over the next six months is predicted to be 10 percent lower than the long-term mean would indicate, a value of 0.90 would be entered for QX. Q_s in Equation 8.8 is thus reduced by 10 percent. The adjusted Q_s and thus Q% is reflected in the computations that create the SFF array from which the IP array is developed.

Reliability and Frequency Analyses

The probability distribution option is activated by inserting a *5CR2* record in the *TABLES* input file. Without a *5CR2* record, the equal-weight option is adopted by default. The equal-weight option signaled by a *5CRM* record remains in effect until a *5CR2* record is read in the sequence of input records. The incremental probability array created by a *5CR2* record is applied for all subsequent *2REL*, *2FRE*, *2FRQ*, and *2RES* records. The routines activated by these records adopt the last *5CR2* record probability array created during the *TABLES* execution.

With activation of the probability array option by a *5CR2* record, all subsequent *2REL*, *2FRE*, *2FRQ*, and *2RES* records incorporate the IP array that assigns probabilities to the CRM simulation sequences. The reliability and frequency analysis computation routines are modified to reflect varying probabilities for the multiple sequences. The modifications to the computations are based on counting each simulation sequence multiple times with the count totaling to 1,000,000. The number of times N_s that each simulation sequence is repeated is proportional to incremental probability P_s as follows.

$$N_s = 1,000,000 P_s \quad (8.21)$$

The procedure is illustrated with an example. A water supply diversion CRM reliability table is being constructed for water rights of interest for some selected month of interest, say July, and also for the entire annual simulation period. Frequency tables are being constructed for regulated and unappropriated flows and end-of-month storage contents for a selected month of interest. A 1940-2013 period-of-analysis is divided into 74 annual simulation sequences for the CRM analysis. The 5CR2 record incremental probability array assigns probabilities to each of the 74 simulation sequences as shown in the second column of Table 8.19. The counts from Eq. 8.21 are shown in the last column of the Table 8.19.

Table 8.19
Example of Applying Probability Array in
Reliability and Frequency Counts

Simulation Sequence	Incremental Probability	N _s Count
1	0.019254	19,254
2	0.025347	25,347
3	0.007469	7,469
4-67	not shown	
73	0.011528	11,528
74	0.017862	17,862
Totals	1.000000	1,000,000

For this example, reliability and frequency analyses for a conventional long-term simulation are based on data from 74 years of simulation results. Likewise, reliability and frequency analyses for a CRM application assuming equally-likely sequences are based on data from 74 simulation sequences. Each sequence is given equal weight and counted one time. However, reliability and frequency analyses for a CRM application using the SFF option is based on data from 74 simulation sequences that are counted as 1,000,000 simulation sequences. The first simulation sequence is counted 19,254 times as shown in the third column of the table above. The second simulation sequence is counted 25,347 times. Thus, the simulation sequences are weighted or counted in proportion to the 5CR2 record probability array.

The reliability and frequency analysis computational routines in *TABLES* count the frequency or number of times that specified magnitudes of specified variables are equaled or exceeded. The algorithms are essentially the same for either a conventional simulation, the CRM equal-weight option, or the CRM probability array option. However, the counts are increased in proportion to incremental probabilities for the CRM probability array option.

Comparison of Examples 8.1, 8.2, 8.3, 8.4 and 8.5

The five conditional reliability modeling examples presented in this chapter are CRM versions of the conventional long-term simulation example presented in the *Fundamentals Manual*. A schematic of the system of 11 control points and six reservoirs and description of the 30 water rights are found in the *Fundamentals Manual*.

A *CR* record, with parameters defined by Table 8.1, is added to the *SIM* input DAT file to convert to a CRM simulation. The alternative *CR* records for the five examples are reproduced below. The *CR* record is the only difference in *SIM* input data between the five CRM examples.

Example 8.1	CR	12	4	0	0.25	
Example 8.2	CR	30	5	0	0.10	
and	CR	30	5	-1	0.10	
Example 8.3:	CR	30	5	0	0.10	2
and	CR	30	5	-1	0.10	2
Examples 8.4 and 8.5:	CR	3	6	0	0.25	

The previous Examples 8.1, 8.2, and 8.3 are based on the equal-weight option, meaning all of the adopted simulation sequences are each weighted the same. In the following two examples, probability array computations are employed to assign varying probabilities to the hydrologic simulation sequences. Probability arrays are computed within program *TABLES*.

Input and Output Files for the Examples

The example in the *Fundamentals Manual* has a *SIM* input dataset consisting of DAT, FLO, and EVA files with the following filenames. *SIM* stores the simulation results in an output file with the filename extension OUT.

FundExam.DAT, FundExam.FLO, FundExam.EVA, FundExam.OUT

The 1940-2012 period-of-analysis in the *Fundamentals Manual* has been extended to 1940-2013 for the FLO and EVA files adopted in the examples presented here. Addition of the *CR* record to the DAT file and extension of the hydrology to 1940-2013 are the main changes to the *SIM* input dataset example from the *Fundamentals Manual* adopted for the five examples presented in this chapter. All five CRM examples include the following input and output files.

CrmExam.DAT	– <i>SIM</i> DAT file FunExam.DAT with <i>CR</i> record added
CrmExam.FLO	– <i>SIM</i> FLO file containing 1940-2013 naturalized flows
CrmExam.EVA	– <i>SIM</i> EVA file with 1940-2013 net evaporation rates
CrmExam.CRM	– <i>SIM</i> output file with CRM simulation results
CrmExam.TIN	– <i>TABLES</i> input file
CrmExam.TMS	– <i>TABLES</i> message file
CrmExam.TOU	– <i>TABLES</i> main output file

Examples 8.4 and 8.5 also employ the following additional files.

CrmExam.OUT	– <i>SIM</i> simulation results for conventional long-term simulation
CrmExam.SFF	– <i>TABLES</i> output file with probability arrays
CrmExam.BRS	– <i>SIM</i> beginning reservoir storage file (Example 8.5 only)
CrmExam.BES	– <i>SIM</i> beginning-ending storage file (Example 8.5 only)

The OUT and CRM files with the *SIM* long-term and short-term simulation results are read by *TABLES*. The *SIM* output OUT file for the conventional long-term simulation is required by the *TABLES* 5CR1 record operations. The 5CR2 record operations in *TABLES* include reading the CRM file created by *SIM*. The flow ratio (percentage) versus exceedance probability table created by the 5CR1 record is optionally written in a storage-flow-frequency (SFF) file for information.

The flow ratio (percentage) versus incremental probability table created by the 5CR2 record is also recorded in the SFF file. TABLES also creates its normal TMS and TOU output files as specified by the records contained in the TIN input file.

The optional BES and BRS files are illustrated by inclusion in Example 8.5. The BES file is used in the long-term SIM simulation to specify beginning-of-simulation storage contents. A BRS file created by SIM from a CRM simulation may be read by TABLES to provide beginning of CRM simulation storage contents. A BRS file is created in Example 8.5 for information only and not actually used in the computations which are based on storage change.

Examples 8.4 and 8.5

For both Examples 8.4 and 8.5, the CR record divides the 1940-2013 period-of-analysis into 74 three-month hydrologic sequences covering June (month 6) through August (month 8). The six reservoirs all have beginning-of-month storage contents at the beginning of each June of 25 percent of their storage capacities. Examples 8.4 and 8.5 differ from each other as follows.

1. Development of the probability array in Example 8.4 focuses on Granger Reservoir. Although the entire basin is simulated, the probability array is designed to maximize the accuracy of the probability estimates at Granger Reservoir. Thus, the probability array for Example 8.4 is developed based on storage in Granger Reservoir and naturalized flow at control point Grang at the Granger dam site.
2. Example 8.5 is concerned with the accuracy of the probability estimates in general for the entire river basin system. The probability array is developed based on storage in all six reservoirs and naturalized flow at control point Hemp at the basin outlet.

Example 8.4 with Probability Array Based on Storage and Flows at Lake Granger

Example 8.4 consists of estimating water supply diversion reliability and reservoir storage and regulated flow frequency metrics for June, July, and August, given that the storage contents of each of the six reservoirs is at 25 percent of capacity at the beginning of June. Lake Granger is adopted for developing the SFF and IP arrays, using the change in storage option. The TABLES input TIN file for Example 8.4 is reproduced as Table 8.20. The TMS, SFF, and TOU output files created by TABLES are shown as Tables 8.22 through 8.26.

The SIM simulation and the TABLES 5CR2 record computations are based on each of the six reservoirs being at 25% capacity at the beginning of June (end of May). The 5CR2 record has a CRVO of 0.00, meaning that the reliability and frequency analyses are based on Lake Granger being at 25% capacity at the end of both May and the preceding November, with no net storage change over this period of six-months. The computed incremental probabilities assigned to the 74 simulation sequences in the IP array will change if a non-zero storage change for Lake Granger is specified for CRSO on the 5CR2 record.

The 5CRI record controls the TABLES computations that develop a storage-flow-frequency (SFF) array for use by the 5CR2 record incremental probability (IP) array computations that assign probabilities to each of the 74 hydrologic simulation sequences. A CRS of 11 months

is specified in columns 23-24 of the *5CRI* record, meaning the SFF array will be developed based on the net storage change during the preceding months of July through May. With a CRS of 11 months entered on the *5CRI* record, storage change in acre-feet is defined as the storage volume at the end of May minus the storage volume at the end of the previous June. A positive storage change indicates 11-month net refilling of the reservoir and a negative change indicates a draw-down. The storage change serves in the probability array computations as an index of preceding hydrologic conditions.

Table 8.20
TABLES Input TIN File for CRM Example 8.4

```

** TABLES Input File CrmExam4.TIN
** CRM Example 8.4
**      1          2          3          4          5          6          7          8
** 567890123456789012345678901234567890123456789012345678901234567890
****-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!
5CR1  1    1    6    3  11    1    1
5CR1FLOW  Grang
5CR1STRE  Grang
5CR2  1    1    0    3  99    1    1    1    0.00
5CR2FLOW  Grang
5CR2STRE  Grang
**      Diversion Reliability Tables
2REL    0
**      Reservoir Storage Frequency Tables
2FRE    6    6
2FRE    6    7
2FRE    6    8
ENDF

```

Hydrologic persistence is modeled by relating naturalized flow volume during June through August at the control point at Granger Dam to the net change in storage in Granger Lake during the preceding 11-month period of July through May. Program *TABLES* computes the preceding storage change in acre-feet for Lake Granger for each June-August simulation sequence by subtracting the storage CRS months earlier from end-of-May storage from the long-term *SIM* simulation results output OUT file. The naturalized flow volume in acre-feet for each hydrologic simulation sequence is the summation of the volumes for June, July, and August.

5CRI record field 15 activates an option to write a table of statistics to the TOU file that includes correlation and regression coefficients. Correlation statistics included in the TOU file are tabulated in Table 8.21 for 14 executions of *TABLES*. Any integer number of months may be specified for CRS on the *5CRI* record for the change in storage volume of Lake Granger. Linear correlation coefficients (Eq. 8.17) and Spearman rank correlations (Eq. 8.18) for the CRS-month change in preceding storage volume versus June-August naturalized flow volume are tabulated in columns 2 and 3 of Table 8.21 for the alternative values for CRS in column 1.

As previously noted, the linear regression equations (Eqs. 8.13–8.15) are applied to transformed variables to obtain the coefficients a, b, and c for the nonlinear regression equations 8.9, 8.10, and 8.12. The linear correlation coefficients (Eq. 8.17) in columns 4 and 5 of Table 8.21 reflect the linear correlation between the transformed variables of the exponential and combined

regression equations (Eqs. 8.9 and 8.11). For the exponential regression equation (Eq. 8.9), the natural logarithm (ln) of Q is regressed with S, resulting in the y-intercept and slope of a straight line plot being represented by ln a and b, respectively. The correlation coefficients in the second column of Table 8.21 correspond directly to the linear regression equation (Eq. 8.11).

Table 8.21
Correlation Coefficients for Alternative 5CR1 Record CRS Options

1 CRS	2 Correlation Coefficient	3 Spearman Coefficient	4 Exponential Correlation	5 Combined Eq. Correlation	6 Number of Sequences
1 month	0.1106	0.2824	0.2175	0.2080	37
2 months	0.2643	0.3269	0.3240	0.2955	43
3 months	0.2089	0.3066	0.3143	0.2015	44
4 months	0.3940	0.4459	0.4516	0.3171	44
5 months	0.3287	0.4926	0.4482	0.3310	47
6 months	0.3435	0.5391	0.4784	0.3519	52
7 months	0.3364	0.5255	0.4757	0.3513	59
8 months	0.4053	0.5884	0.5667	0.3882	66
9 months	0.3903	0.5688	0.5371	0.3734	64
10 months	0.4498	0.6154	0.5957	0.4456	52
11 months	0.4399	0.6438	0.6067	0.4494	49
12 months	0.3204	0.5476	0.5272	0.3242	51
Total w Limits	0.1081	0.3218	0.3703	0.1207	36
Total w/o Lim	0.3115	0.5999	0.6132	0.3001	74

The exponential regression equation (Eq. 8.9) provides the best fit as indicated by having the highest (closest to 1.00) correlation coefficients and is adopted for the analysis. Based on the correlation coefficients tabulated in Table 8.21, a value of 11 months is adopted for CRS. With a CRS of 11 months, application of linear correlation (Eq. 8.17) to the 11-month storage change S versus the natural logarithm of 3-month Q results in the correlation coefficient (r) of 0.6067 shown in Table 8.24 and Table 8.21. The statistics shown in Tables 8.24 and 8.21 for a CRS of eleven months include a linear correlation coefficient for storage change versus flow volume of 0.4399. The corresponding Spearman correlation coefficient of 0.6438 is the linear correlation coefficient for the storage rank versus flow rank.

With a CR2 of 6 months and CRS of 4 months or more, the 74 potential sequences are reduced to accommodate the preceding storage change period extending back to before the January 1940 beginning of the 1940-2013 hydrologic period-of-analysis. With a CRS of 11 months, the first simulation sequence adopted for the regression analysis relates naturalized flow volume during June 1941 through August 1941 to change in storage of Granger Lake from the end-of-June 1940 to the end-of-May 1941.

The number of hydrologic sequences included in the computations and listed in column 6 of Table 8.21 is also reduced from 74 by specification of lower and upper limits of 10 acre-feet

and 65,400 acre-feet for storage in Granger Lake in columns 66-76 of the 5CR1 record. Granger Lake has a storage capacity of 65,500 acre-feet. Zero storage change for a full and spilling reservoir or completely empty reservoir is considered to be non-homogeneous with the other storage changes and therefore excluded from the regression analysis by specifying the limits of 10 acre-feet and 65,400 acre-feet. Correlation coefficients are significantly increased by imposing these limits. In developing the SFF array, hydrologic sequences with storage volumes during both the end-of-November and end-of-May falling outside the specified range of 10 acre-feet to 65,400 acre-feet are excluded from the regression computations.

For CRS of 11 months, the 49 simulation sequences listed in Table 8.22 remain after application of the upper and lower storage limits eliminate 24 of the 74 sequences and the first sequence is omitted as discussed earlier. After developing the SFF array, all 74 simulation sequences are used in developing the IP array and in all further computations.

The last two rows of Table 8.21 reflect alternative *TABLES* executions with a CRS of zero, meaning total storage at the end of May, rather than change in storage, is employed to model hydrologic persistence in assigning probabilities to simulation sequences. The next-to-last row reflects the storage limits of 10 acre-feet and 65,400 acre-feet. These limits are removed from the 5CR1 record for the execution of *TABLES* that produced the statistics in the last row of Table 8.21. The improvement in correlation coefficients without the storage limits indicated by the last row of Table 8.21 is related to 36 versus 74 sequences being adopted. For the non-zero values of CRS, inclusion of the storage limits improves the correlation coefficients.

The 5CR1 record in the TIN file of Table 8.20 controls the development of the SFF relationship which is a two-dimensional array (table) of exceedance probability versus naturalized stream flow volume expressed as a percentage of the flow volume predicted with a regression equation. The resulting array is tabulated in the SFF file reproduced as Table 8.23. 5CR1 record computations use storage and flow data obtained by reading the OUT file for a conventional long-term *SIM* simulation. The net 11-month changes in storage volume during July through May in Lake Granger are correlated with 3-month (June–August) volumes of naturalized flows at control point Grang which is the dam site. FILE2 option 5 activated in 5CR1 column 80 results in creation of a listing in the TMS file of Table 8.22 with the following information for each of the 49 hydrologic simulation sequences used in the regression analysis.

- storage volume of Lake Granger at the end of May in acre-feet
- 11-month net change in storage contents of Lake Granger from July through May in acre-feet
- 3-month total of June-August naturalized flow volume in acre-feet

June-August naturalized flow volume (Q) at control point Grang is related to the eleven-month net change in storage in Lake Granger preceding the beginning-of-June in the 5CR1 record operations with the exponential regression equation. For the exponential model of Equation 8.9, the natural logarithm of the flow volume Q is regressed with the storage volume S using standard least squares linear regression (Eqs. 8.13, 8.14, 8.15). The resulting coefficients shown in Table 8.24 are as follows.

$$Q = 6,472.34 e^{(S / 30,884.7)}$$

Table 8.22
TABLES Message TMS File for CRM Example 8.4

TABLES MESSAGE FILE

```
*** File was opened: CrmExam4.TIN
*** File was opened: CrmExam4.TOU
*** Identifiers for the 18 records in the TIN file were checked.
*** File was opened: CrmExam.CRM
*** File was opened: CrmExam.OUT
*** Tables are being developed as specified by a 5CR1 record.
```

FILE2 option 5 results in the following
tabulation of arrays developed by 5CR1 record.

Sequence	Storage	Stor Change	Nat Flow
1	59204.6	-4607.1	6403.0
2	17385.5	-28687.0	11983.0
3	4151.0	-15575.6	7214.0
4	24440.3	24440.3	5837.0
5	22364.2	-355.1	5274.0
6	1514.2	1514.2	162.0
7	9222.9	9222.9	19658.0
8	1140.3	-10943.2	240.0
9	65500.0	65500.0	92636.0
10	49122.0	-16378.0	19528.0
11	65500.0	13739.8	8307.0
12	63029.5	7075.8	33799.0
13	65500.0	600.7	15992.0
14	38911.7	-26588.3	1483.0
15	11051.4	-24111.4	4219.0
16	65500.0	55971.4	39852.0
17	27078.6	-38421.4	2728.0
18	65500.0	41155.8	58392.0
19	14599.8	-50900.1	10307.0
20	23007.0	12392.9	20920.0
21	65500.0	32979.1	34019.0
22	1603.5	-63896.5	1515.0
23	65500.0	65500.0	74563.0
24	19834.7	10287.2	248018.0
25	62432.9	-3067.1	33975.0
26	22933.5	-42566.5	14540.0
27	33288.2	3989.5	10471.0
28	43061.9	6972.0	1660.0
29	65500.0	27438.9	24598.0
30	42220.6	-23279.4	2513.0
31	65500.0	27397.4	24002.0
32	31792.1	-33707.9	2370.0
33	65500.0	38807.2	114774.0
34	23660.8	-41839.2	336.3
35	65500.0	45980.8	9280.9
36	11804.5	-10883.2	5361.9
37	65500.0	53572.0	12301.8
38	51865.8	51865.8	64455.8
39	28718.2	24114.0	8235.4
40	65500.0	38668.4	144408.7
41	13454.9	-52045.1	9817.6
42	9970.3	-1839.7	6694.6
43	65500.0	54463.8	276989.9
44	25666.9	-39833.1	260.8
45	2793.9	-18608.7	211.0
46	63826.4	63826.4	8839.9
47	25761.3	-30142.7	193.8

Table 8.22 Continued
TABLES Message TMS File for CRM Example 8.4

48	45577.6	33398.9	7895.0
49	7425.5	7425.5	8346.7

*** Tables are being developed as specified by a 5CR2 record.
 *** Tables are being developed as specified by a 2REL record.
 *** Tables are being developed as specified by a 2FRE record.
 *** Tables are being developed as specified by a 2FRE record.
 *** Tables are being developed as specified by a 2FRE record.

Program TABLES output is in file CrmExam4.TOU

Date: 05/12/2015
 Time: 16:53:55

***** Normal Completion of Program TABLES *****

Table 8.23
 SFF and IP Arrays from SFF File for CRM Example 8.4

SFF Array		Probability IP Array		IP Array Continued	
Flow %	Frequency	Flow %	Frequency	Flow %	Frequency
2,279.332	0.000000	2121.738	0.022882	403.751	0.017367
2,200.501	0.018519	1330.132	0.004610	39.867	0.026172
2,121.669	0.037037	783.868	0.018660	1930.678	0.012501
1,716.402	0.055556	57.328	0.026147	5.657	0.028323
1,263.668	0.074074	958.796	0.005490	156.119	0.021354
884.866	0.092593	871.542	0.011721	90.196	0.024759
845.193	0.111111	259.759	0.001453	206.936	0.002508
837.192	0.129630	158.106	0.004144	1084.247	0.006649
720.792	0.148148	107.708	0.021748	138.532	0.002860
615.708	0.166667	201.573	0.017352	2429.180	0.004628
453.692	0.185185	121.351	0.016367	165.147	0.005008
442.232	0.203704	17.579	0.026266	112.614	0.024697
441.827	0.222222	98.187	0.023446	4659.404	0.004628
432.689	0.240741	88.717	0.052117	4.387	0.011884
384.025	0.259259	2.725	0.021172	3.549	0.025270
363.300	0.277778	330.678	0.006245	148.701	0.026861
333.620	0.296296	4.037	0.025390	3.260	0.007584
245.595	0.314815	1558.283	0.009026	132.806	0.005806
221.849	0.333333	299.458	0.006257	140.405	0.007618
188.441	0.351852	328.492	0.003284	sum =	1.000000
185.188	0.370370	139.737	0.000773		
156.948	0.388889	568.552	0.000685		
151.677	0.407407	269.010	0.004176		
151.225	0.425926	24.946	0.007761		
141.710	0.444444	70.970	0.064786		
119.273	0.462963	670.373	0.009175		
115.056	0.481481	435.510	0.033946		
110.502	0.500000	45.889	0.032277		
105.641	0.518519	982.245	0.003067		
97.467	0.537037	498.659	0.030968		
96.127	0.555556	559.536	0.003994		
93.857	0.574074	173.380	0.003604		
85.083	0.592593	351.907	0.007122		
78.755	0.611111	572.253	0.001814		

78.284	0.629630	711.754	0.009460
77.882	0.648148	1289.053	0.000842
76.299	0.666667	844.628	0.019651
71.420	0.685185	255.200	0.001883
61.636	0.703704	25.485	0.008209
54.242	0.722222	1254.266	0.004903
44.639	0.740741	98.406	0.012382
43.442	0.759259	4172.051	0.004628
43.127	0.777778	355.457	0.016567
30.672	0.796296	571.513	0.000212
30.535	0.814815	124.463	0.004728
27.618	0.833333	210.623	0.012999
24.200	0.851852	603.255	0.007300
9.877	0.870370	2916.641	0.004628
6.939	0.888889	244.586	0.013381
4.866	0.907407	176.139	0.016771
3.947	0.925926	27.924	0.031134
3.891	0.944444	413.777	0.008365
3.757	0.962963	1514.462	0.004666
2.970	0.981481	1288.953	0.000749
0.000	1.000000	42.273	0.022147

The variable $Q\%$ (Eq. 8.8) is defined as the June-August flow volume at control point Grang expressed as a percentage of the flow volume computed by the regression equation as a function of 11-month net change in storage contents of Lake Granger. The random variable $Q\%$ is modeled with the Weibull formula as specified by DIST of 1 in column 28 of the *5CRI* record. The alternative DIST option is to apply the log-normal probability distribution. The resulting table of $Q\%$ versus exceedance probability is tabulated in the SFF file reproduced as Table 8.23.

The *5CR2* record uses the $Q\%$ versus exceedance probability array to develop the $Q\%$ versus incremental probability array which is also recorded in Table 8.23. The *5CR2* record routine reads the June-August flow volumes for the 74 sequences from the *SIM* CRM file. The preceding 11-month net storage change is specified by the parameters CSVO and CSV on the *5CR2* record. A net storage volume change in Lake Granger during July through May of 0.0 acre-feet is specified for CSV in this example. Any other positive (increase) or negative (decrease) in storage contents can be specified for CSV depending on the actual conditions being modeled. The regression equation and coefficients developed with the *5CRI* record are applied to develop a $Q\%$ for each of the 74 flow sequences. Incremental probabilities are assigned to each sequence based on interpolation of the $Q\%$ versus exceedance probability array.

The incremental probability (IP) array tabulated in the second half of Table 8.23 assigns a probability to each of the 74 hydrologic sequences. For example, the first two sequences (June-August 1940 and June-August 1941) have probabilities of 0.022882 and 0.004610. With the alternative equal-weight option, each sequence would have a probability of $1/74 = 0.0135135$.

The only purpose of the *5CRI* record is to develop a $Q\%$ versus exceedance probability array to be used in the *5CR2* record computations. The sole purpose of the *5CR2* record is to develop a $Q\%$ versus incremental probability array. The incremental probability array is used in *2FRE*, *2FRQ*, *2REL*, and *2RES* record operations to assign probabilities to each of the hydrologic sequences in the frequency and reliability analyses.

CRM Frequency and Reliability Analysis Results

The *TABLES* input TIN file of Table 8.20 creates the *TABLES* output TOU file shown as Tables 8.24, 8.25, and 8.26. The *2REL* water supply diversion reliability indices and *2FRE* storage frequency statistics are presented in Tables 8.25 and 8.26. Reliability and frequency tables have the same format and interpretation with either of the alternative equal-weight or probability array methods for estimating probabilities.

Discussion of Alternative Options

With either the equal-weight or probability array CRM strategies, initial or preceding reservoir storage volume is specified in the *SIM* input data, is employed with each simulation, and significantly affects the *SIM* simulation results. Reservoir storage also plays another very different role in the probability array methodology that is not incorporated in the equal-weight strategy. Reservoir storage or change in reservoir storage is employed by the program *TABLES* to incorporate hydrologic persistence in assigning probabilities to each of the simulation sequences. The reservoir storage contents at the beginning of the simulation sequences reflects essentially the entire history of hydrologic conditions contributing to stream inflows to the reservoir and water surface evaporation as well as the specified constant scenario of water demands and operations. The alternative option of employing only net change in storage over a specified number of months preceding the simulation period allows the model to correlate future hydrologic conditions to the recent past. Selection of preceding time period is largely judgmental but can be aided by the statistics illustrated by Table 8.21.

The initial storage contents at the beginning of the long-term January 1940 through December 2013 simulation (end of December 1939) is not known. The TCEQ WAM System datasets, *Fundamentals Manual* example, and the present Example 8.4 adopt the common approach of beginning a conventional long-term simulation with all reservoirs full to conservation storage capacity. Alternatively, *SIM* has a beginning-ending storage (BES) option that sets the initial storage equal to end-of-simulation storage for a long-term simulation. This would reduce the number of sequences eliminated in the SFF computations due to full reservoirs. The BES file option is employed for the long-term *SIM* simulation of the following Example 8.5.

The probability array computations in Example 8.4 are performed using storage contents of Lake Granger and naturalized flow volumes at the dam site. The Example 8.4 strategy enhances the accuracy of probability estimates that support frequency and reliability analysis for Lake Granger. Example 8.5 employs a broader basin-wide strategy.

Table 8.24
5CR1 Record Statistics from TOU File for CRM Example 8.4

5CR1 RECORD STATISTICS FOR SFF RELATIONSHIP

Beginning-of-month storage contents in month 6
Naturalized flows for 3 months beginning in month 6
Change in storage for 11 month(s) (CRS =11)

Storage in reservoir(s): Grang
Flows at control point(s): Grang

Storage and Flow Statistics:

	Storage	Flow (Q)	(Q/Qp) 100%
Mean	4898.5	30930.2	267.339
Std Dev	34572.7	57063.7	432.832
Minimum	-63896.5	162.0	2.383
Maximum	65500.0	276989.9	2746.409

Linear correlation coefficient for storage versus flow volume = 0.4399
Spearman correlation coefficient for storage versus flow volume = 0.6438

Regression and correlation coefficients for FIT = 1

Exponential Regression, $Q = a \cdot \exp^{(S/b)}$, a = 6472.343 b = 30884.710 R = 0.6067

Table 8.25
Reliability Table from TOU File for CRM Example 8.4

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 6
Length of simulation period (CR1) is 3 months.
Initial storage multiplier (CR4) = 0.250

NAME	TARGET	MEAN	*RELIABILITY*	PERCENTAGE OF MONTHS								PERCENTAGE OF SEQUENCES							
	DIVERSION (AC-FT/SQ)	SHORTAGE (AC-FT/SQ)	PERIOD VOLUME (%)	WITH DIVERSIONS EQUALING OR EXCEEDING			PERCENTAGE OF TARGET DIVERSION AMOUNT												
			(%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%		
PK	82724.1	4989.77	89.05	93.97	89.0	89.0	90.6	91.3	94.9	95.7	99.9	73.1	73.1	77.8	79.9	87.1	100.0	100.0	
Whit	5850.0	5211.16	10.64	10.92	10.6	10.6	10.6	10.7	10.7	10.7	10.7	7.1	7.1	7.1	7.3	7.3	11.0	13.9	
WacoL	26260.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
WacoG	24095.8	5142.33	73.83	78.66	73.8	75.4	75.5	78.6	81.7	82.7	83.3	38.0	41.5	41.6	48.8	58.5	87.7	100.0	
High	33420.8	10131.57	62.52	69.68	62.5	63.1	63.1	67.3	72.3	78.4	82.7	26.6	28.2	29.4	30.4	40.4	77.1	100.0	
Belton	58550.3	4494.72	90.72	92.32	90.7	90.7	90.7	91.1	93.5	93.5	93.5	76.8	76.8	78.0	78.0	80.4	97.3	100.0	
George	8254.7	793.02	88.05	90.39	88.0	88.0	88.0	88.8	89.6	91.4	94.2	69.9	69.9	69.9	70.4	74.1	98.4	100.0	
Grang	13537.5	1107.38	88.61	91.82	88.6	89.4	89.4	89.4	89.5	91.3	93.5	95.8	68.3	70.7	71.0	72.6	81.8	98.0	
Camer	112343.9	44408.02	32.11	60.47	32.1	32.6	33.9	37.0	55.3	94.5	100.0	5.2	5.2	5.4	5.6	23.5	75.8	100.0	
Bryan	48588.0	8378.41	42.72	82.76	42.7	42.7	45.7	74.3	98.9	99.0	99.1	13.9	13.9	18.5	31.5	66.6	97.3	100.0	
Hemp	418614.2	76642.58	34.07	81.69	34.1	37.9	43.0	75.9	90.1	94.6	99.9	9.6	10.6	18.0	38.3	72.1	95.5	100.0	
Total	832239.2	161298.97			80.62														

Table 8.26
Reservoir Storage Frequency Statistics from TOU File for CRM Example 8.4

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 6

CONDITIONAL RELIABILITY MODELING: Probability Array Option
 Annual cycles starting in month 6
 Length of simulation period (CR1) is 3 months.
 Initial storage multiplier (CR4) = 0.250

RESERVOIR	STANDARD		PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	164972.	106229.	16937.	17761.	17761.	19548.	36443.	94527.	135067.	154990.	160440.	201810.	328403.	570240.
Whit	225822.	95490.	152326.	152413.	152413.	154042.	155057.	162740.	180926.	194074.	208687.	238976.	317291.	627100.
WacoL	69678.	36126.	38455.	38455.	38455.	39342.	42492.	44426.	48950.	57662.	64077.	79612.	116368.	192100.
Belton	125532.	63542.	9440.	9440.	9440.	67555.	83985.	95772.	101694.	106750.	120648.	143396.	201765.	457600.
George	9374.	6354.	907.	907.	907.	1574.	6339.	6666.	6835.	7223.	8114.	9429.	17944.	37100.
Grang	17593.	12816.	0.	0.	0.	0.	6504.	12420.	13304.	13602.	15981.	19465.	32596.	65500.
Total	612908.	277117.	318660.	319361.	319361.	323864.	333377.	415231.	513684.	536219.	573804.	671046.	1113191.	1949640.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 7

CONDITIONAL RELIABILITY MODELING: Probability Array Option
 Annual cycles starting in month 6
 Length of simulation period (CR1) is 3 months.
 Initial storage multiplier (CR4) = 0.250

RESERVOIR	STANDARD		PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	124466.	133014.	0.	0.	0.	0.	0.	9792.	39810.	73900.	128655.	208616.	302378.	570240.
Whit	236364.	96600.	147699.	149730.	149730.	150337.	150830.	169118.	186495.	206284.	221789.	277924.	379000.	627100.
WacoL	65837.	42554.	27223.	27223.	27223.	29889.	31846.	34292.	43562.	52631.	55823.	71683.	145856.	192100.
Belton	84511.	79015.	0.	0.	0.	0.	0.	0.	67701.	76285.	87660.	116483.	204730.	457600.
George	5604.	7914.	0.	0.	0.	0.	0.	0.	3578.	3668.	4585.	6662.	16562.	37100.
Grang	8537.	12981.	0.	0.	0.	0.	0.	0.	1179.	6327.	9057.	9964.	16602.	65500.
Total	525343.	326728.	177058.	182240.	182240.	184298.	185323.	308597.	370836.	454774.	482494.	664487.	1053193.	1949640.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 8

CONDITIONAL RELIABILITY MODELING: Probability Array Option
 Annual cycles starting in month 6
 Length of simulation period (CR1) is 3 months.
 Initial storage multiplier (CR4) = 0.250

RESERVOIR	STANDARD		PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	94612.	136083.	0.	0.	0.	0.	0.	0.	0.	2671.	59907.	166409.	305411.	570240.
Whit	241565.	94752.	141311.	146436.	146436.	146954.	147471.	169443.	190515.	211554.	239412.	283116.	379000.	627100.
WacoL	59676.	44468.	16432.	19158.	19494.	21110.	21400.	29290.	39682.	43281.	50174.	75801.	140575.	192100.
Belton	49605.	76673.	0.	0.	0.	0.	0.	0.	0.	0.	42229.	79238.	157407.	444923.
George	2492.	5643.	0.	0.	0.	0.	0.	0.	0.	0.	996.	2717.	5435.	35201.
Grang	4353.	9665.	0.	0.	0.	0.	0.	0.	0.	0.	18.	5353.	12715.	65500.
Total	452348.	322208.	158998.	168871.	168871.	170194.	173996.	223938.	277442.	306737.	378249.	560718.	918810.	1917514.

**Example 8.5 with Probability Arrays Based on
Storage in Six Reservoirs and Flows at the Outlet**

Example 8.5 uses the same *SIM* input dataset as Example 8.4, except Example 8.5 incorporates the beginning-ending-storage BES file reproduced below as Table 8.27. The BES file is used to begin the long-term *SIM* simulation with the end-of-simulation storage. The *SIM* simulation results output OUT file from the long-term simulation is used by the *TABLES 5CR1* record computations in developing the storage-flow-frequency (SFF) array. The BES file could optionally also be employed in Example 8.4, rather than assuming that all reservoirs are full to capacity at the beginning of the long-term *SIM* simulation.

Table 8.27
Beginning Reservoir Storage (BES) File for Example 7.5 Long-Term Simulation

Beginning-Ending Storage (BES) File

Reservoir ID		Storage Capacity	Beginning Storage	Ending Storage
1	PK	570240.00	20433.20	20433.20
2	Whit	627100.00	388929.97	388929.97
3	WacoL	192100.00	192100.00	192100.00
4	Belton	457600.00	159619.80	159619.80
5	George	37100.00	37100.00	37100.00
6	Grang	65500.00	65500.00	65500.00
Totals		1949640.0	863682.9	863683.0

The optional beginning reservoir storage BRS file created by the *SIM CRM* simulation is reproduced below as Table 8.28 for information. The BRS file represents one of several options that can be employed to input initial storage for use in the *TABLES 5CR2* record computations in developing the incremental probability (IP) array. However, since storage change rather than storage was adopted in Example 8.5 with *5CR2* record CSVO option 99, the BRS file was not actually needed. Creation of BRS and BRS files is specified by parameters on the *JO* record.

Table 8.28
Beginning Reservoir Storage (BRS) File for Example 8.5 CRM Simulations

Beginning Reservoir Storage (BRS) File

Reservoir		Control Point	Storage Capacity	Beginning Storage
1	PK	1 PK	570240.0	142560.0
2	Whit	2 Whit	627100.0	156775.0
3	WacoL	3 WacoL	192100.0	48025.0
4	Belton	6 Belton	457600.0	114400.0
5	George	7 George	37100.0	9275.0
6	Grang	8 Grang	65500.0	16375.0

The first several records of the DAT file for the convention long-term simulation used by the 5CR1 record routine to develop a SFF array is shown in Table 8.29. BES option 4 was activated in JO record column 32 to create the BES file of Table 8.27 with the long-term simulation but deactivated with BES of zero for the CRM simulation as shown in Table 8.30.

Table 8.29
First Several Records of SIM Input DAT file for Example 8.5 Long-Term Simulation

```

**          1          2          3          4          5
**345678901234567890123456789012345678901234567890123456
**-----!-----!-----!-----!-----!-----!-----!
JD      74      1940          1          -1          -1          4
JO       2
**CR     3          6          0          0.25
RO      -1

```

As specified by the CR1 of 3 and CR2 of 6 entered in the CR record reproduced in Table 8.30, the 1940-2013 hydrologic period-of-analysis is subdivided into 74 three-month simulation sequences consisting of June, July, and August of each year. The storage contents of each of the six reservoirs is set at 25 percent of capacity.

Table 8.30
First Several Records of SIM Input DAT file for Example 8.5 CRM Simulation

```

**          1          2          3          4          5
**345678901234567890123456789012345678901234567890123456
**-----!-----!-----!-----!-----!-----!-----!
JD      74      1940          10          -1          -1          4
JO       2
CR       3          6          0          0.25
RO      -1

```

JD record ICHECK option 10 creates a CRM trace in the SIM message MSS file. The first two years (1940-1941) and last year (2013) of the hydrologic period-of-analysis trace is shown in Table 8.31. The trace parameters are defined as follows.

Month is the month counter which advances from 1 for January 1940 to 888 for December 2013.

CRMM is the month counter for CRM computations which goes from 1 to $74 \times 3 = 222$ months.

Seq which advances from 1 to 74 is the counter for the CRM simulation sequences.

Cycle is the number of cycles which is always one cycle for the annual cycle option unless CR1 exceeds 12 months.

Month of the simulation sequence with 1, 2, and 3 denoting June, July, and August.

CRWRITE denotes whether the simulation results for each month are included in the CRM output file. A zero for *CRWRITE* means the simulation results for that month are written to the CRM file. A -99 indicates that the simulation results are not included in the CRM file.

Year is the year which goes from 1940 to 2013.

Month from 1 to 12 denotes the months January through December.

Table 8.31
First 18 Months and Last 12 Months of 888-Month CRM Trace from MSS File

CRM Information for ICHECK Option 10							
Month	CRMM	Seq	Cycle	Month	File	Year	Month
1	0	0	1	0	-99	1940	1
2	0	0	1	0	-99	1940	2
3	0	0	1	0	-99	1940	3
4	0	0	1	0	-99	1940	4
5	0	0	1	0	-99	1940	5
6	1	1	1	1	0	1940	6
7	2	1	1	2	0	1940	7
8	3	1	1	3	0	1940	8
9	3	1	1	3	-99	1940	9
10	3	1	1	3	-99	1940	10
11	3	1	1	3	-99	1940	11
12	3	1	1	3	-99	1940	12
13	3	1	1	3	-99	1941	1
14	3	1	1	3	-99	1941	2
15	3	1	1	3	-99	1941	3
16	3	1	1	3	-99	1941	4
17	3	1	1	3	-99	1941	5
18	4	2	1	1	0	1941	6
877	219	73	1	3	-99	2013	1
878	219	73	1	3	-99	2013	2
879	219	73	1	3	-99	2013	3
880	219	73	1	3	-99	2013	4
881	219	73	1	3	-99	2013	5
882	220	74	1	1	0	2013	6
883	221	74	1	2	0	2013	7
884	222	74	1	3	0	2013	8
885	222	74	1	3	-99	2013	9
886	222	74	1	3	-99	2013	10
887	222	74	1	3	-99	2013	11
888	222	74	1	3	-99	2013	12

Of the total of 12(years)(cycles)= 888 months, the 666 months flagged with CRWRITE of -99 were excluded from the simulation results CRM file.

Hydrologic persistence is modeled by relating naturalized flow volume during June through August at control point Hemp (the basin outlet) to either the preceding storage change or the storage in the six reservoirs. *5CRI* record field 15 activates an option to write a table of statistics to the TOU file that includes correlation and regression coefficients. Correlation statistics are tabulated in Table 8.32 for 14 executions of *TABLES* with different alternative values of CRS entered on the *5CRI* record for each execution. If CRS is entered as a positive integer on the *5CRI* record, program *TABLES* computes the preceding six-reservoir storage change in acre-feet for each June-August simulation sequence by subtracting the end-of-month storage CRS months earlier from the end-of-May storage. The default (blank or zero) CRS adopts the total preceding (end of May) storage volume rather than change in storage volume. The naturalized flow volume in acre-feet for each hydrologic simulation sequence is the summation of the volumes for control point Hemp for June, July, and August. Linear correlation coefficients (Eq. 8.17) and Spearman rank correlations (Eq. 8.18) for either the change in preceding storage volume or the preceding storage

volume versus June-August naturalized flow volume are tabulated in columns 2 and 3 of Table 8.32 for the alternative values for CRS in column 1.

Table 8.32
Correlation Coefficients for Alternative 5CR1 Record CRS Options

1 CRS	2 Correlation Coefficient	3 Spearman Coefficient	4 Exponential Correlation	5 Combined Eq. Correlation	6 Number of Sequences
1 month	0.1162	0.1490	0.1444	0.1711	63
2 months	0.2533	0.2666	0.3018	0.2563	65
3 months	0.3286	0.2607	0.3337	0.2649	70
4 months	0.3475	0.3362	0.3750	0.3169	71
5 months	0.3968	0.3902	0.4228	0.3947	71
6 months	0.3996	0.3980	0.4238	0.3602	72
7 months	0.4227	0.4275	0.4510	0.3614	73
8 months	0.4209	0.4080	0.4353	0.3807	73
9 months	0.4110	0.3926	0.4157	0.3696	73
10 months	0.4044	0.3815	0.4019	0.3427	72
11 months	0.3813	0.3702	0.3794	0.3329	68
12 months	0.4177	0.3800	0.4017	0.3960	68
14 months	0.3295	0.3495	0.3320	0.2893	70
16 months	0.2573	0.2823	0.2722	0.1704	72
Total w Limits	0.2262	0.3032	0.3187	0.2262	59
Total w/o Lim	0.2957	0.3762	0.3912	0.2962	74

The six reservoirs have a combined total conservation storage capacity of 1,949,640 acre-feet. Zero storage change for a full and spilling reservoir is considered to be non-homogeneous with the other storage changes and therefore excluded from the computations developing the SFF array by specifying an upper storage limit of 1,949,500 acre-feet. In developing the SFF array, hydrologic sequences with storage volumes during both the end-of-May and the beginning of the CRS period falling outside the specified range of 0.0 to 1,949,500 acre-feet are not used in developing the SFF array. This results in the number of sequences adopted for the SFF computations being reduced from 74 to the numbers shown in column 6 of Table 8.32.

The last two rows of Table 8.32 reflect alternative *TABLES* executions with a CRS of zero, meaning total storage at the end of May, rather than change in storage, is employed to model hydrologic persistence in assigning probabilities to simulation sequences. The next-to-last row reflects the upper storage limit of 1,949,500 acre-feet. This limit is removed from the *5CR1* record for the execution of *TABLES* that produced the statistics in the last row of Table 8.32.

With a CR2 of 6, the change in storage is defined as the storage contents in acre-feet at the end of May (beginning of June) minus the corresponding storage volume CRS months earlier. In developing the SFF array from the long-term *SIM* simulation results recorded in the OUT file, with

CR2 of 6 (June), for the first sequence, with CRS of 4 or greater, the storage change period extends back to before the beginning of the simulation (January 1940). In this case, the first sequence is not used in the regression analysis, though all 74 sequences are used later in the IP array computations.

A CRS of 7 months (5CR1 record column 24) is adopted for Example 8.5 somewhat arbitrarily based on judgment and the statistics in Table 8.32. The 74 three-month June-August naturalized flow volumes (acre-feet) at control point Hemp and the corresponding total December-May preceding change in storage contents (acre-feet) of the six reservoirs are tabulated in the TMS file of Table 8.34. The following coefficients from Tables 8.36 and 8.32 provide an index of the correlation linear between these 3-month flow volumes in acre-feet at control point Hemp and preceding 7-month storage change of the six reservoirs.

$$\begin{aligned} \text{Linear correlation coefficient (r)} &= 0.4227 \\ \text{Spearman rank correlation coefficient (r}_r\text{)} &= 0.4275 \end{aligned}$$

The linear regression equations (Eqs. 8.13–8.15) are applied to transformed variables to obtain the coefficients a, b, and c for the nonlinear regression equations 8.9, 8.10, and 8.12. The linear correlation coefficients (Eq. 8.17) in the second column of Table 8.32 correspond directly to the linear regression equation shown earlier as Eq. 8.11. The linear correlation coefficients (Eq. 8.17) in columns 4 and 5 of Table 8.32 reflect the linear correlation between the transformed variables of the exponential and combined regression equations (Eqs. 8.9 and 8.10).

For the exponential regression equation (Eq. 8.9), the natural logarithm (ln) of Q is regressed with S, resulting in the y-intercept and slope of a straight line plot being represented by ln a and b, respectively. The exponential regression equation (Eq. 8.9) provides the best fit as indicated by having the highest (closest to 1.00) correlation coefficients. Application of linear correlation (Eq. 8.17) to the seven-month storage change S versus the natural logarithm of Q results in the correlation coefficient (r) of 0.4510 shown in Tables 8.36 and 8.32.

The *TABLES* input TIN, message TMS, storage-flow-frequency array SFF, and output TOU files for Example 8.5 are reproduced as Tables 8.33–8.38. The 5CR1 and 5CR2 records in Table 8.33 relate the annual June through August volumes of naturalized flows at control point Hemp to the change in total storage volume in the six reservoirs during the preceding seven months. Flow volume is related to preceding storage using exponential regression (Eq. 8.9). The random variable Q% is modeled with the Weibull formula. The alternative option would be to apply the log-normal probability distribution. Regression and correlation statistics are shown in Table 8.36. The following regression equation with coefficients shown in Table 8.36 is adopted for use in developing the SFF array.

$$Q = 600,472 e^{(S / 960,828)}$$

The storage-flow-frequency SFF and incremental probability IP arrays can be recorded in the SFF file using switch parameters FILE2 and FILEO on the 5CR1 and 5CR2 records. The SFF and IP arrays are tabulated in Table 8.35.

Table 8.33

TABLES Input TIN File for CRM Example 8.5

```

** TABLES Input File CrmExam3.TIN
** CRM Example 8.5
**      1      2      3      4      5      6      7      8
** 567890123456789012345678901234567890123456789012345678901234567890
****----!----!----!----!----!----!----!----!----!----!----!----!----!----!----!----!
5CR1  1    6    6    3    7    1    1                                     1949500.    4
5CR1FLOW      Hemp
5CR1STRE      PK      Whit      WacoL      Belton      George      Grang
5CR2  1    6    0    3    99   1    1    1    0.0
5CR2FLOW      Hemp
5CR2STRE      PK      Whit      WacoL      Belton      George      Grang
**      Diversion Reliability Table
2REL
**      Reservoir Storage Frequency Tables
2FRE  6    6
2FRE  6    7
2FRE  6    8
ENDF

```

Table 8.34
TABLES Message TMS File for CRM Example 8.5

```

TABLES MESSAGE FILE

*** File was opened: CrmExam5.TIN
*** File was opened: CrmExam5.TOU
*** Identifiers for the 18 records in the TIN file were checked.
*** File was opened: CrmExam.CRM
*** File was opened: CrmExam.OUT
*** Tables are being developed as specified by a 5CR1 record.

FILE2 option 4 results in the following tabulation
of arrays developed by 5CR1 or 5COR records.

Sequence      Storage      Flow      Storage Rank Flow Rank
  1      794875.8      3354824.0      68.      71.
  2      16398.9      1534722.0      28.      55.
  3      -12405.1      366753.0      25.      18.
  4      456041.8      1235206.0      58.      50.
  5      662245.7      1366911.0      63.      53.
  6         5529.4      1025551.0      27.      45.
  7      213174.5      714433.0      44.      34.
  8         90690.5      499547.0      35.      29.
  9      434572.4      734207.0      57.      39.
 10      162700.8      1004171.0      40.      43.
 11      -544198.9      440247.0       2.      24.
 12         86062.3      232878.0      32.      6.
 13      390348.3      486615.0      54.      27.
 14      157806.9      210812.0      39.      5.
 15      414129.5      586610.0      56.      32.
 16      -201638.5         62778.0      12.      1.
 17      1427589.5      2094484.0      73.      65.
 18         17893.8      719618.0      29.      36.
 19      -310952.8      878081.0       9.      40.
 20         -1010.3      726137.0      26.      37.
 21      139620.7      1959494.0      37.      63.
 22      -187721.8      963200.0      13.      42.
 23      -68786.7      306284.0      20.      13.
 24      -148104.3      295306.0      15.      11.

```

Table 8.34 Continued
TABLES Message TMS File for CRM Example 8.5

25	1121691.4	1019416.0	72.	44.
26	580500.6	625667.0	62.	33.
27	-392615.5	489223.0	6.	28.
28	837511.9	2597231.0	69.	69.
29	363035.1	460837.0	50.	25.
30	385246.1	413444.0	53.	21.
31	-446881.2	733955.0	4.	38.
32	89816.4	353481.0	34.	17.
33	537199.1	1698325.0	60.	59.
34	-182232.5	346328.0	14.	16.
35	288969.2	1607507.0	47.	57.
36	-23008.7	1429990.0	24.	54.
37	301099.8	428587.0	48.	22.
38	-410391.8	716067.0	5.	35.
39	708333.4	2535006.0	66.	68.
40	115381.1	247005.0	36.	8.
41	-98506.8	2516210.0	18.	67.
42	56690.7	1574298.0	30.	56.
43	-23182.6	542116.0	23.	31.
44	-223840.5	141687.0	11.	4.
45	858797.8	402506.0	71.	20.
46	86608.4	1707045.0	33.	60.
47	64187.9	3078269.0	31.	70.
48	-257203.2	390152.0	10.	19.
49	483026.2	1733968.0	59.	61.
50	699944.9	1047569.0	65.	46.
51	200538.2	1137060.0	42.	47.
52	140343.4	2495621.0	38.	66.
53	206103.4	1286302.0	43.	52.
54	260429.0	522987.0	46.	30.
55	242227.6	1697035.0	45.	58.
56	-536604.9	327177.0	3.	15.
57	687550.3	1742622.0	64.	62.
58	-47756.8	72149.0	21.	2.
59	367696.2	463067.9	51.	26.
60	-47150.0	1991133.0	22.	64.
61	718382.9	280321.1	67.	10.
62	376735.6	1155529.0	52.	48.
63	-125797.8	1251894.0	17.	51.
64	336239.0	3823800.0	49.	72.
65	168950.2	1187588.4	41.	49.
66	-369501.0	238455.0	7.	7.
67	852854.6	5477529.0	70.	73.
68	-133640.2	308883.8	16.	14.
69	-333514.0	295515.0	8.	12.
70	556323.8	954215.0	61.	41.
71	-620998.6	96350.8	1.	3.
72	405488.2	278552.0	55.	9.
73	-69142.0	429342.1	19.	23.

*** Tables are being developed as specified by a 5CR2 record.
 *** Tables are being developed as specified by a 2REL record.
 *** Tables are being developed as specified by a 2FRE record.
 *** Tables are being developed as specified by a 2FRE record.
 *** Tables are being developed as specified by a 2FRE record.
 Program TABLES output is in file CrmExam5.TOU

Date: 07/06/2015
 Time: 15:14:04

***** Normal Completion of Program TABLES *****

Table 8.35
SFF and IP Arrays from SFF File for CRM Example 8.5

<u>SFF Array</u>		<u>Probability IP Array</u>	
Flow %	Frequency	Flow %	Frequency
494.748	0.000000	350.696	0.016881
479.514	0.013514	558.698	0.005442
464.279	0.027027	255.586	0.033972
448.769	0.040541	61.077	0.019099
375.493	0.054054	205.706	0.016822
359.129	0.067568	227.639	0.009382
348.273	0.081081	170.791	0.012790
282.191	0.094595	118.979	0.013542
259.780	0.108108	83.192	0.013813
251.261	0.121622	122.272	0.037878
247.155	0.135135	167.230	0.014534
244.283	0.148649	73.317	0.010968
243.916	0.162162	38.783	0.009516
237.649	0.175676	81.039	0.014762
219.640	0.189189	35.108	0.047016
202.112	0.202703	97.692	0.021033
201.985	0.216216	10.455	0.012023
198.174	0.229730	348.806	0.003214
195.018	0.243243	119.842	0.003309
194.611	0.256757	146.232	0.046366
182.792	0.270270	120.928	0.007544
180.910	0.283784	326.326	0.004232
174.671	0.297297	160.407	0.011426
172.859	0.310811	51.007	0.002481
169.811	0.324324	49.179	0.002820
165.885	0.337838	169.769	0.006614
161.702	0.351351	104.196	0.015322
153.691	0.364865	81.473	0.002768
141.885	0.378378	432.532	0.022723
141.180	0.391892	76.746	0.011453
130.018	0.405405	68.853	0.014094
129.176	0.418919	122.230	0.005586
127.972	0.432432	58.867	0.016205
122.596	0.445946	282.832	0.000170
121.055	0.459459	57.676	0.027426
117.631	0.472973	267.707	0.006078
114.265	0.486486	238.144	0.034213
95.305	0.500000	71.375	0.010412
95.244	0.513514	119.251	0.001704
92.486	0.527027	422.169	0.001244
89.063	0.540541	41.135	0.004801
84.917	0.554054	419.039	0.000605
84.201	0.567568	262.177	0.005716
78.943	0.581081	90.282	0.024327
77.786	0.594595	23.596	0.044494
76.836	0.608108	67.032	0.008438
75.699	0.621622	284.284	0.000607

69.721	0.635135	512.642	0.005442
69.636	0.648649	64.974	0.016749
66.418	0.662162	288.768	0.000606
63.485	0.675676	174.458	0.028610
61.871	0.689189	189.361	0.019822
59.116	0.702703	415.610	0.016021
58.335	0.716216	214.215	0.007302
57.375	0.729730	87.096	0.017215
56.946	0.743243	282.617	0.004432
54.793	0.756757	54.487	0.056990
53.983	0.770270	290.209	0.003840
53.614	0.783784	12.015	0.010231
52.827	0.797297	77.117	0.016741
52.597	0.810811	331.595	0.002576
52.596	0.824324	46.683	0.003109
52.173	0.837838	192.437	0.015663
46.110	0.851351	208.485	0.003280
36.480	0.864865	636.799	0.005442
35.460	0.878378	197.776	0.029655
30.623	0.891892	39.711	0.001651
30.418	0.905405	912.204	0.005442
29.790	0.918919	51.440	0.039286
29.786	0.932432	49.214	0.002037
27.422	0.945946	158.911	0.009934
22.103	0.959459	16.046	0.015737
12.896	0.972973	46.389	0.004130
12.628	0.986486	71.501	0.002195
0.000	1.000000	sum =	1.0000000

The *SIM* simulation and the *TABLES 5CR2* record computations are based on each of the six reservoirs being at 25% capacity at the beginning of June (end of May). The *5CR2* record has a CRVO of 0.00, meaning that the reliability and frequency analyses are based on the storage contents of the six reservoirs being at 25% capacity at the end of both May and the preceding October, with no net storage change over this period of seven months. The computed incremental probabilities assigned to the 74 simulation sequences in the IP array will change if a non-zero storage change is specified for CRSO on the *5CR2* record.

Reliability and frequency tables are presented as Tables 8.37 and 8.38 can be compared with the corresponding Example 8.4 Tables 8.24 and 8.25. All of the 11 control points are included in the water supply reliability tables, and all six reservoirs are included in the storage frequency tables for both examples. However, development of the storage-flow-frequency (SFF) relationship upon which the reliability and frequency estimates are based differ between the two examples. The SFF relationship in Example 8.4 is designed for maximum accuracy in estimating reliabilities and frequencies associated with Granger Reservoir. The SFF relationship in Example 8.5 is designed for more general applicability in estimating reliabilities and frequencies associated with all of the reservoirs and control points throughout the river basin.

A variety of *5CR1* and *5CR2* options can be combined in various ways to develop storage-flow-frequency (SFF) relationships. A variety of stream flow locations and time periods may also

be considered. Frequency and reliability estimates may vary significantly with different computational methods and choices of locations and time periods. The alternative CRM options are compared in the last section of this chapter.

Table 8.36
5CR1 Record Statistics from TOU File for CRM Example 8.5

5CR1 RECORD STATISTICS FOR SFF RELATIONSHIP

Beginning-of-month storage contents in month 6
Naturalized flows for 3 months beginning in month 6
Change in storage for 7 month(s) (CRS = 7)

Storage in reservoir(s): PK Whit WacoL Belton George Grang
Flows at control point(s): Hemp

Storage and Flow Statistics:

	Storage	Flow(Q)	(Q/Qp) 100%
Mean	174668.5	1070519.0	137.822
Std Dev	404022.7	980176.9	109.345
Minimum	-620998.6	62778.0	12.628
Maximum	1427589.5	5477529.0	479.514

Linear correlation coefficient for storage versus flow volume = 0.4227
Spearman correlation coefficient for storage versus flow volume = 0.4275

Regression and correlation coefficients for FIT = 1
Exponential Regression, $Q = a \cdot \exp^{(S/b)}$, a = 600471.850 b = 960828.095 R = 0.4510

Table 8.37
Water Supply Diversion Reliability Table from TOU File for CRM Example 8.5

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 6
Length of simulation period (CR1) is 3 months.
Number of simulations and months = 74 and 222 (CR3= 0)
Initial storage multiplier (CR4) = 0.250

NAME	TARGET	MEAN	*RELIABILITY*	PERCENTAGE OF MONTHS										PERCENTAGE OF SEQUENCES							
	DIVERSION (AC-FT/SQ)	SHORTAGE (AC-FT/SQ)	PERIOD VOLUME (%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%				
EK	82724.1	4293.10	91.05	94.81	91.0	91.0	92.2	92.3	94.7	96.3	99.6	77.3	77.3	80.8	81.1	88.9	100.0	100.0			
Whit	5850.0	5247.17	9.97	10.30	10.0	10.0	10.0	10.1	10.1	10.1	10.1	6.0	6.0	6.0	6.3	6.3	9.5	14.4			
WacoL	26260.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0			
WacoG	24095.8	4222.95	75.19	82.47	75.2	78.4	79.5	81.3	85.7	86.3	88.6	44.5	52.9	53.7	57.3	65.7	89.3	100.0			
High	33420.8	8516.56	68.56	74.52	68.6	69.4	69.9	73.2	77.5	82.5	86.3	37.5	39.2	40.3	41.1	52.4	82.3	100.0			
Belton	58550.3	4978.20	89.44	91.50	89.4	89.4	89.4	89.8	92.8	92.8	92.8	74.3	74.3	75.3	75.3	78.3	98.5	100.0			
George	8254.7	1024.93	84.81	87.58	84.8	84.8	84.8	85.3	86.9	88.9	92.4	60.7	60.7	60.7	61.2	66.8	99.6	100.0			
Grang	13537.5	1688.78	83.99	87.53	84.0	84.1	84.1	85.0	86.9	89.2	93.2	59.0	59.3	59.7	62.5	71.1	93.9	100.0			
Carner	112343.9	39999.04	34.66	64.40	34.7	35.8	38.7	44.2	60.2	91.4	100.0	8.6	8.6	10.9	11.2	40.1	72.0	100.0			
Bryan	48588.0	6968.75	46.91	85.66	46.9	46.9	50.8	82.8	98.2	99.3	99.7	17.7	17.7	27.1	44.9	70.5	99.0	100.0			
Hemp	418614.2	72457.92	39.92	82.69	39.9	43.9	50.4	77.1	90.0	95.2	99.5	13.6	17.7	30.2	53.5	69.7	96.2	100.0			
Total	832239.4	149397.41			82.05																

Table 8.38
Reservoir Storage Frequency Statistics from TOU File for CRM Example 8.5

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 6

CONDITIONAL RELIABILITY MODELING: Probability Array Option
 Annual cycles starting in month 6
 Length of simulation period (CR1) is 3 months.
 Initial storage multiplier (CR4) = 0.250

RESERVOIR	STANDARD		PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	176225.	139989.	16937.	16937.	17761.	23198.	25531.	52891.	125606.	149272.	160440.	264268.	358682.	570240.
Whit	211736.	75536.	152326.	152413.	152413.	154107.	155316.	161551.	180926.	189592.	196889.	222475.	296277.	627100.
WacoL	66835.	31753.	38455.	38455.	39245.	39342.	42492.	44382.	47453.	57662.	62580.	86057.	97556.	192100.
Belton	125094.	61809.	9440.	9440.	15420.	15420.	83985.	94049.	101694.	106190.	123473.	143396.	196682.	457600.
George	10748.	7506.	907.	907.	1574.	1574.	6338.	6588.	7203.	8290.	9218.	11694.	21492.	37100.
Grang	18563.	13468.	0.	0.	0.	0.	0.	12364.	12805.	13616.	18725.	23394.	39171.	65500.
Total	609232.	285999.	318660.	318660.	319361.	323864.	333377.	356982.	489618.	532636.	573804.	738802.	1009482.	1949640.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 7

CONDITIONAL RELIABILITY MODELING: Probability Array Option
 Annual cycles starting in month 6
 Length of simulation period (CR1) is 3 months.
 Initial storage multiplier (CR4) = 0.250

RESERVOIR	STANDARD		PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	139224.	154966.	0.	0.	0.	0.	0.	0.	29956.	98880.	146910.	231267.	403803.	570240.
Whit	226853.	88740.	147699.	148038.	148038.	150337.	151030.	165360.	180028.	187324.	216810.	261742.	379000.	627100.
WacoL	67660.	45517.	27223.	27223.	27866.	28288.	31177.	34292.	42738.	52034.	57483.	83032.	164166.	192100.
Belton	91008.	90586.	0.	0.	0.	0.	0.	0.	56361.	78111.	101629.	133040.	222719.	457600.
George	7913.	11054.	0.	0.	0.	0.	0.	0.	0.	4328.	6079.	7769.	28570.	37100.
Grang	10744.	16748.	0.	0.	0.	0.	0.	0.	0.	1440.	9057.	13673.	30292.	65500.
Total	543447.	361016.	177058.	177058.	179215.	184298.	184983.	228051.	357762.	423130.	564379.	750748.	1053193.	1949640.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 8

CONDITIONAL RELIABILITY MODELING: Probability Array Option
 Annual cycles starting in month 6
 Length of simulation period (CR1) is 3 months.
 Initial storage multiplier (CR4) = 0.250

RESERVOIR	STANDARD		PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
PK	116990.	156098.	0.	0.	0.	0.	0.	0.	0.	51654.	104837.	166409.	419045.	570240.
Whit	242436.	94392.	141311.	141931.	141931.	146954.	147471.	172639.	201158.	225574.	233542.	283116.	379000.	627100.
WacoL	63596.	46654.	16432.	16432.	17687.	19494.	22199.	29518.	37323.	45782.	57140.	81045.	161151.	192100.
Belton	63820.	83396.	0.	0.	0.	0.	0.	0.	0.	18343.	70899.	121201.	157407.	444923.
George	3559.	7575.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3950.	11362.	35201.
Grang	6614.	13880.	0.	0.	0.	0.	0.	0.	0.	0.	1848.	6286.	16950.	65500.
Total	497045.	352968.	158998.	159871.	159871.	173996.	180095.	233859.	269188.	349518.	486237.	681912.	930149.	1917514.

Summary Comparison of CRM Options

Water supply, hydroelectric power, and environmental instream flow reliabilities and reservoir storage levels over the next several months or years depend on both the:

1. amount of water currently available in reservoir storage
2. hydrology that occurs over the future period of interest as represented by naturalized stream flows and net reservoir evaporation rates

Beginning reservoir storage and naturalized stream flow represent the two sources of available water. The relative importance of these two sources in determining supply reliabilities and end-of-period storage frequencies depends upon their relative magnitude. Beginning reservoir storage is specified by the model-user the same with either the equal-weight or probability array options. The probability array option methodology deals with the hydrology, focusing on improving probability estimates assigned to each of the individual hydrologic sequences.

The final results of CRM analyses are organized in the format of frequency and reliability tables created using the *TABLES 2FRE* and *2REL* record routines. Other types of tables and plots may be created as well. The format and content of displays of CRM results are the same regardless of the options adopted to perform the computations. Of course, the numerical values of the estimates of reliability and frequency metrics will vary depending on the computational techniques chosen. The choices of computational options are outlined in Table 8.39.

Table 8.39
Outline of CRM Computational Options

-
1. Equal-Weight Option
 - * choice of annual or monthly cycle options (*CR* record)
 2. Probability Array Option (*CR* record, *5CRI* and *5CR2* records)
 - Flow-Frequency (FF) Relationship Option
 - * choice of annual or monthly cycle options
 - * selection of control points for naturalized flows
 - * upper and lower limits defining reservoir storage range
 - * choice of log-normal or Weibull (Eq. 8.19 or Eq. 8.20)
 - Storage-Flow-Frequency (SFF) Relationship Option (Eq. 8.8)
 - * choice of annual or monthly cycle options
 - * choice of number of months for defining storage change
 - * selection of control points for storages and flows
 - * upper and lower limits defining reservoir storage range
 - * choice of regression equation (Eq. 8.9, 8.10, 8.11, or 8.12)
 - * choice of log-normal or Weibull (Eq. 8.19 or Eq. 8.20)
-

Choice of Annual or Monthly Cycle Options

CRM is based on repeating the *SIM/SIMD* simulation with many sequences of naturalized flows and net evaporation rates, starting each simulation with the same initial storage condition. The *CR* record that activates the CRM mode of simulation is the only *SIM/SIMD* record associated with conditional reliability modeling. The annual cycle and monthly cycle options are set by the *CR* record entries listed in Table 8.1. Either the annual option or monthly cycle option can have simulation lengths of any integer number of months, which may equal, exceed, or be less than 12 months. The defining difference between the options is that the annual cycle starts each simulation in the same month of the year, but the monthly cycle varies the starting month. Each annual cycle begins 12 months later than the preceding cycle begins. With the monthly cycle option, each cycle begins one month later than the preceding cycle begins.

With the annual cycle option, each hydrologic sequence begins in the same month and thus the multiple simulations all reflect the same seasonal sequencing. The annual cycle option has the advantage of capturing seasonality, but the disadvantage of limiting the number of simulations to the number of years in the total period-of-analysis or fewer. The monthly cycle option allows up to 12 times more simulations than the annual cycle option. The accuracy of reliability estimates depends both on properly modeling seasonal characteristics of hydrology and maximizing the number of hydrologic sequences used in the CRM analysis. The choice of which option to adopt for a particular application depends upon the relative importance of these two considerations. The annual cycle option is the standard choice for most applications since seasonality is usually very important.

Simulation Sequences Exceeding 12 Months

The length of the CRM hydrologic simulation sequences specified by CR1 can be any number of months ranging from one month to the total long-term hydrologic period-of-analysis, which for example for 1940-2013 is 888 months. However, CR1 is typically 12 months or less and expected to seldom exceed several years for practical applications. Two alternative annual sequencing options are available if the CRM simulation period CR1 exceeds 12 months. With 1940-2013 hydrology, annual cycle option, CR1 of 30 months, and starting month CR2 of 5 (May), the default CR5 option 1 illustrated by Table 8.2 results in 72 thirty-month CRM simulations with the same months being included in multiple simulations. CR5 option 2 results in the 24 thirty-month sequences (total=24x30=720 months) shown in Table 8.3 with each of the 888 months of 1940-2013 being included in no more than one sequence.

The cycling employed with the default CR5 option 1 provides the advantage of increasing the number of hydrologic simulation sequences incorporated in the CRM. The alternative CR5 option 2 subdivides the hydrologic period-of-analysis without repeating any months, which may be advantageous in certain situations in which hydrology developed either within or external to the WRAP modeling system is to be employed in defined sequential order.

Many of the program *TABLES* routines are designed to function based on user-selection of a month ranging from January through December, with *SIM* simulation results being read for the 12 months of the year. For CR1 exceeding 12 months, CR3 options allow selection of any specified 12-month period for inclusion in the *SIM* CRM simulation results output file.

SOU and DSS output files created by *SIM* place no limit on the length of the simulation sequences that can be recorded in their tables and plots. DSS files created directly with *SIM* rather than *TABLES* treat each individual CRM sequence of any length as a separate DSS record which facilitates plotting and otherwise managing and analyzing CRM simulation results.

Choice of Relative Frequency or Log-Normal Probability Distribution Function

The *2FRE* record frequency analysis options allow application of either relative frequency (Eq. 8.4) or alternatively either the log-normal or normal probability distributions (Eqs. 8.6 and 8.7) to monthly values of the random variable of interest for either CRM equal-weight or non-CRM applications. These options can be applied for either long-term simulation or equal-weight CRM frequency analyses. Relative frequency (Eq. 8.4) is the standard choice for most applications.

The log-normal is usually preferable to the normal distribution in modeling stream flow and reservoir storage since negative volumes have zero probability. The log-normal probability distribution provides additional information for modeling flow and storage volumes compared to relative frequency, assuming the volumes are actually log-normally distributed. Relative frequency does not presume that the storage or flow volumes are accurately represented by any particular probability function.

Equations 8.5 and 8.20 are alternative expressions for relative frequency. The *2FRE* record frequency computations are based on the relative frequency formula $P=n/N$ (Eq. 8.5). The *5CR1* record computations performed to develop a FF or SFF array use the Weibull formula $P=m/N+1$ (Eq. 8.20).

When applying the probability array CRM options, the *2FRE* record relative frequency option is combined with either the relative frequency option or log-normal option for developing the FF or SFF arrays controlled by the *5CR1* record. The methodology for developing a storage-flow-frequency (SFF) array applies optionally either the Weibull relative frequency formula or the log-normal probability distribution to the random variable $Q\%$ (Eq. 8.8) determined from natural flow volume summed over a specified time period. The methodology for developing a flow-frequency (FF) array applies optionally either the Weibull formula or the log-normal distribution directly to the natural flow volumes summed over a specified time period.

Choice of Equal-Weight or Probability Array Options

The *SIM* simulation is the same for the equal-weight method and the flow-frequency (FF) or storage-flow-frequency (SFF) variations of the probability array method. The hydrologic simulation sequences are defined on the *CR* record in the same manner for each of these strategies. The probability array options are employed in the post-simulation program *TABLES*.

All of the hydrologic simulation sequences may be weighted the same in the reliability and frequency analysis computations. Alternatively, probabilities may be assigned to each simulation sequence that may vary between sequences depending upon preceding reservoir storage or change in storage. The default equal-weight option simplifies the CRM computations and reduces requirements for the model-user to select further sub-options. If the equal-weight option is

adopted, the only CRM input is the *SIM/SIMD CR* record. However, the equal-weight option ignores the correlation of natural stream flows and net reservoir evaporation rates to preceding reservoir storage conditions that reflect past hydrology. The probability array approach is designed to incorporate correlation with preceding storage conditions into the assigning of probabilities to the hydrologic sequences.

The random variable defined by the model-user in applying the probability array methodology is naturalized stream flow volume at a single control point or the sum of flows at selected multiple control points. The flow volumes are for a specified length of time. Flow volumes are related to storage volumes or changes thereof in one or more selected reservoirs. Thus, the method is defined in terms of specific locations in the river/reservoir system and specific time periods for aggregating flow volumes. The enhanced accuracy of the probability array option is most applicable if focused on one or a few reservoirs and stream flow sites. In this regard, the equal-weight option may be advantageous if many reservoirs and diversion sites scattered over a large river basin are being investigated. For example, the equal-weight option may facilitate the analysis of six reservoirs and diversions at 11 locations at both the end of June and September based on a single execution of *SIM* and *TABLES*. Multiple runs of *TABLES* with CRM parameters varied depending on location and timeframe of interest will typically be required to best achieve the potential enhancements in probability estimation offered by the probability array methodology.

The storage-flow-frequency (SFF) form of the probability array strategy uses either reservoir storage at a point in time or change in storage over a specified length of time as an index of past hydrologic conditions. Storage or storage changes reflect past histories of precipitation, stream flow inflows, evaporation, water demands, and other hydrologic factors. High storage levels result from past wet conditions that are more likely to be followed by continued wet conditions. Severe reservoir draw-downs imply dry weather that may be followed by continued dry conditions. The optional methods in *TABLES* are designed to further improve estimates of the probabilities associated with each of the multiple hydrologic sequences based on the information provided by a known fixed preceding reservoir storage dynamics.

Improvements in probability estimates provided by the probability array option relative to the equal-weight option depend on the degree of correlation that exists between either preceding storage or change in preceding storage and subsequent naturalized flow volumes. The correlation for a short future period will typically be greater than for a longer period. The naturalized flow volume during a month has a greater correlation with storage at the beginning of the month than the correlation of the flow volume during a year to the storage at the beginning of the year. For typical river systems, the correlation of natural flow to preceding reservoir storage may not necessarily be high.

The validity or accuracy of CRM is not necessarily highly dependent on significant correlation of naturalized flow with preceding reservoir storage or change thereof. CRM with the equally-likely option or flow-frequency (FF) relationship option is a valid and useful analysis methodology even with no correlation between stream flow volume and preceding reservoir storage volume or preceding change in storage volume. However, if a significant correlation does exist, using a SFF relationship to assign flow probabilities should enhance the accuracy of CRM estimates.

Linear, Spearman, and nonlinear correlation coefficient values provided by the 5CRI record provide useful indices for assessing the degree of correlation. Graphical analyses of naturalized flow versus storage performed external to the WRAP programs are also useful.

Water availability depends upon both beginning-of-simulation reservoir storage and naturalized stream flow along with other factors. Beginning reservoir storage is specified by the model-user. If water supply is dominated by releases or withdrawals from storage in a large reservoir, the accuracy of water supply reliability estimates may be relative insensitive to the accuracy of estimates of the probability of naturalized stream flows.

Further Comparison of Equal-Weight and Probability Array Computation Strategies

The frequency metrics presented in Table 8.40 for the storage contents of Granger Reservoir at the end of August, given that the storage contents at the beginning of June is 25 percent of its capacity of 65,500 acre-feet, were computed alternatively using the equal-weight, FF array, and SFF array methodologies. The analyses summarized in Table 8.40 are based on the SIM simulation results for Example 8.4. The annual cycle option is employed. The simulation length CR1 is 3 months with starting month CR2 of June. The same SIM simulation input and results from Example 8.4 are used with all four of the alternative analyses presented in the table. All differences are controlled by parameters entered in the TABLES input TIN file.

Table 8.40
End-of-August Storage-Frequency Metrics for Granger Reservoir for
Initial Storage Volume of 16,375 acre-feet (25 Percent of Capacity) at the Beginning of June

1	2	3	4	5	6
Month	Equal Weight	FF Array	SFF Mean	SFF Regression	Example 8.4
<u>End-of-August Storage Contents (acre-feet)</u>					
Mean	9,080	9,396	9,396	5,300	4,353
St Dev	17,355	17,741	17,741	11,737	9,665
50%	0.0	0.0	0.0	0.0	0.0
40%	2,964	2,430	2,430	0.0	18.5
30%	6,297	6,300	6,300	6,077	4,809
25%	8,518	7,095	7,095	7,045	5,353
20%	12,031	11,860	11,860	9,951	6,300
15%	25,933	26,931	26,931	12,715	9,951
10%	41,320	49,189	49,189	12,760	12,715
5%	59,658	59,549	59,549	12,760	26,931
2%	65,031	65,500	65,500	64,523	27,933
1%	65,000	65,500	65,500	65,500	59,912
Max	65,000	65,500	65,500	65,500	65,500

The equal-weight approach consists simply of employing a 2FRE record to perform a frequency analysis of the end-of-August storage volumes for each of the 74 annual three-month simulation sequences generated from the 1940-2013 hydrologic period-of-analysis. The random

variable is end-of-August storage volume (acre-feet) in Lake Granger. Exceedance frequencies (F) are computed with Eq. 8.4 for each of the 74 simulations, and linear interpolation is applied to obtain the frequency relationship tabulated in the first two columns of Table 8.40.

$$F = \frac{n}{N} (100\%) \quad (8.4)$$

Although incremental probabilities are not actually computed with the equal-weight method, conceptually each of the 74 end-of-August storage volumes has a probability of occurrence of $P=1/74 = 0.0135135$. However, certain hydrologic conditions will be represented by many similar sequences while other less likely hydrologic conditions will be represented by fewer sequences. Thus, the hydrologic conditions represented by each of the 74 individual simulation sequences are not equally likely to occur.

Results from the FF array method are shown in the third column of Table 8.40. The Weibull formula (Eq. 8.20) is applied to assign exceedance probabilities (P) to each of the 74 simulations. The random variable is volume of naturalized flow (acre-feet) during June through August. The exceedance probabilities are converted to incremental probabilities of 0.200000 for the sequences with the largest and smallest 3-month flow volumes and $P=1/75=0.013333$ for each of the 72 other sequences. The 74 incremental probabilities sum to 1.000000. The end-of-August storage volumes of Lake Granger for each of the 74 sequences are assigned the probabilities computed for the 3-month naturalized flows associated with the sequences.

$$P = \frac{m}{N+1} \quad (8.20)$$

The metrics in the 4th column of Table 8.40 were computed by applying the SFF array option with FIT option 5, which means the expected or predicted value of the naturalized flow used in developing the SFF array is set equal to the average of the 74 June-August flow volumes from the long-term simulation, rather than regressing flow volume with preceding storage volume. Equation 8.20 is applied to Q% defined by Eq. 8.8 rather than directly to the 3-month flow volumes. With FIT option 5, the expected value of flow Q_s in Eq. 8.8 is set equal to the long-term mean flow, and thus preceding storage (hydrologic condition) is not considered in assigning probabilities. In this case, the FF array and SFF array methods produce the same results. Columns 3 and 4 of Table 8.40 are identical.

The frequency metrics presented in the first four columns are computed by assigning probabilities to each of the 74 hydrologic simulation sequences without consideration of the preceding hydrologic condition. Identically the same results are generated with the FF array method versus applying the SFF array method with the Q_s in Eq. 8.8 set equal to the long-term average of June-August naturalized flow volumes. The equal-weight method provides similar but not identical results since the computational methodology is different.

This example illustrates the fundamental issue of hydrologic persistence. Hydrologic persistence means that dry conditions often tend to persist over extended periods of time, and likewise wet months tend to be followed by wet months. In a long-term non-CRM 1940-2013 simulation, the median (50% exceedance) beginning-of-June (end-of-May) storage is 97.4% of

capacity. Lake Granger is full to 100% capacity at the beginning of June in 36 of the 74 years of the simulation. The beginning-of-June storage contents is at 25% capacity or below during only 9 years. A beginning of June storage contents of 25% capacity in this example represents very dry conditions preceding the beginning of the hydrologic simulation sequences. Therefore, of the 74 CRM hydrologic simulation sequences, the sequences with lower flow volumes logically should be assigned higher probabilities than those sequences with higher flow volumes. The SFF array methodology addresses this issue of hydrologic persistence.

The 5th column of Table 8.40 presents the results of applying the SSF array option with the exponential regression equation. Only 36 of the 74 years of the long-term simulation are used in developing the SFF array since years with Lake Granger completely full or empty at the beginning of June are excluded from the regression.

Example 8.4 results are in the last column of Table 8.40. Example 8.4 is significantly different conceptually than the analysis reflected in the other columns of Table 8.40 in that it includes the significant additional information that Lake Granger is at 25% capacity 11 months earlier as well as at the beginning-of-June. This implies extended preceding dry conditions.

SFF and FF Probability Array Options

If the equal-weight option is adopted, the discussion stops here. The *TABLES 5CR1* and *5CR2* records are not applicable to the equal-weight option. The remainder of this chapter addresses options specified on the *5CR1* and *5CR2* records.

The probability array options consist of a set of computational methods in *TABLES* organized into two major tasks controlled by *5CR1* and *5CR2* records, respectively. The *5CR1* record develops a relationship between exceedance probability and either naturalized flow volume or the flow volume expressed as a percentage of flow computed by a regression equation as defined by Eq. 8.8. These two alternative relationships define the flow-frequency (FF) option and the storage-flow-frequency (SFF) option. The SFF array is based on regressing naturalized flow volume with either preceding reservoir storage or preceding change in reservoir storage. The *5CR2* record uses the FF or SFF relationship to build an incremental probability (IP) array assigning probabilities to each of the multiple hydrologic simulation sequences. The incremental probability (IP) array is used by the *2FRE*, *2FRQ*, *2REL*, and *2RES* record routines in their frequency and reliability analysis computations.

Water availability during a CRM simulation depends upon both the volume of water in storage in reservoirs at the beginning of the hydrologic simulation sequence and the naturalized stream flow volume occurring during the CRM simulation sequence. With the SFF array approach, reservoir storage is used to assign probabilities for hydrology (naturalized flow and net reservoir evaporation rate) sequences as well as to supply water. Beginning reservoir storage is specified by the model-user for all of the alternative equal-weight and probability array CRM strategies. The same preceding storage volume input to the model by the user can be used in assigning probabilities to each of the multiple hydrologic simulation sequences. Alternatively, change in storage may be used to assign the probabilities. Change in storage contents will likely capture hydrologic persistence more accurately than storage contents. However, using change in storage makes CRM applications more complicated than simply using storage.

The model-user may specify lower and upper limits defining a reservoir storage range on the 5CR1 record. Only those naturalized flow sequences with a preceding storage falling within the specified range are used in building the FF or SFF relationship. Thus, the FF or SFF relationship may be built using only flow sequences that follow storage contents that are reasonably representative of the initial storage that will be considered in the analysis.

The multiplier factor QX entered on the 5CR2 record, with a default of 1.0, can be used to adjust the SFF and IP probability arrays for considerations other than preceding storage changes or preceding storage. Storage and naturalized flow volumes from long-term *SIM* simulation results are used to develop coefficients for a selected regression equation. The calibrated regression model is then applied with an inputted value of preceding storage or change thereof to compute the expected value of the flow volume used to develop the SFF array. This expected value represents a long-term mean flow based on conditions represented by the long-term *SIM* simulation. The expected value of flow can be adjusted by multiplying by QX entered on the 5CR2 record. For example, if based on information regarding current El Niño–Southern Oscillation (ENSO) conditions or other climate teleconnections, naturalized flow volumes during the CRM simulation period are expected to be 15 percent lower than long-term expected value (average) conditions would indicate, a QX of 0.85 may be input on the 5CR2 record.

With the FF option, the reservoir storage range provides the only mechanism for incorporating storage in the assigning of probabilities to hydrologic sequences. The SFF option is based on the flow ratio of Eq. 8.8, which explicitly incorporates preceding storage or storage change in the assigning of probabilities. The random variable is naturalized flow volume with the FF option and the Eq. 8.8 flow ratio with the SFF method. Thus, the SFF option is more detailed than the FF option in modeling the correlation between flows and preceding storage or storage change. The FF option is applicable if there is little or no correlation. Again, the correlation of flow volume to preceding storage volume depends upon the length of the time period over which the flows occur. Plots and correlation coefficients provide information that is useful in evaluating the degree of correlation, but choices are based largely on judgment.

Either the FF or SFF relationship may be modeled with either the log-normal probability distribution or Weibull relative frequency equation. The Weibull formula is based on relative frequency which means equally weighting all of the sequences used to develop the FF or SFF relationship. With an extremely large number of hydrologic sequences, the Weibull equation should accurately capture the actual probability distribution of the flow volumes. With a limited sample size, the log-normal distribution provides the advantage of contributing additional information by adopting a probability distribution that reasonably characterizes flow volumes. The log-normal distribution is widely applied in hydrology to model various hydrologic variables including flow volumes. It provides a smooth exceedance frequency curve. The log-normal distribution option is also advantageous over the Weibull probability equation in extrapolating probabilities for flow volumes in the IP array that fall outside the range of volumes used in building the FF or SFF relationship. The Weibull formula may be most applicable for developing a SFF relationship using the monthly cycle option or annual cycle option with many sequences. The log-normal distribution may be preferable for a small number of sequences.

The sum of naturalized flow volumes at any number of control points covering a defined number of months is correlated with the sum of the preceding change in reservoir storage volume

over any number of months at any number of control points or in any number of reservoirs. The model-user selects the control points and reservoirs that are most applicable to the particular application. The preceding and future time periods over which storage and flow volumes are defined for purposes of building the SFF or FF relationship and IP array is also user-specified. The future period is not restricted to CR1 on the *CR* record that defines the length of the simulation sequences, though CR1 is the default. The correlation coefficient tables developed using the *5CR2* record supplemented by plots developed external to WRAP provide information that is useful in evaluating the degree of correlation related to various alternative choices of time periods and control points. However, these choices are governed largely by logical judgments regarding physical relationships inherent in river basin hydrology. Sensitivity analyses may be performed to evaluate the effects of various options on CRM results.

CHAPTER 9 DETECTING ERRORS AND IRREGULARITIES IN DATA FILES

Blunders are inevitable in compiling voluminous input datasets. Detecting and correcting input errors is fundamental to computer modeling. The WRAP programs include features designed to help detect missing and erroneous records in input files. The modeling system features outlined in this chapter facilitate finding many types of errors that violate format rules or result in detectable inconsistencies. However, the discussion in this chapter does not pertain to those situations in which incorrect simulation results are obtained from reasonable but wrong numbers being input in the proper format.

The following features of *SIM*, *SIMD*, *TABLES*, *HYD*, and *DAY* facilitate locating errors.

- tracking of progress in reading input and performing computations
- error messages accompanied by termination of program execution
- warning messages alerting users to possible peculiarities without stopping execution

The system for tracing progress and for checking and reporting errors and irregularities is similar in all of the WRAP programs. This chapter focuses on *SIM/SIMD*, *TABLES* and *HYD*. An array of checking routines in the programs write error and warning messages. Program execution is terminated in conjunction with error messages but continues with warnings. The WRAP programs all create message files that should be routinely examined by model users.

Locating Errors in SIM and SIMD Input Data

The progress of the *SIM* and *SIMD* simulation is tracked by trace messages written to the monitor and message MSS file. Simulation results are written to the monthly OUT or daily SUB file as computed, providing a mechanism for detailed tracking of the simulation computations. Numerous error and warning checks automatically detect irregularities in input data.

Tracking Simulation Progress

The following features trace the progress of the *SIM* or *SIMD* simulation.

- Messages appearing on the monitor during model execution provide a general overview of simulation progress.
- Input trace messages written to the message file confirm that various input records were read and various other tasks were accomplished.
- The output file shows intermediate results of the simulation computations.

SIM or *SIMD* execution begins with an interactive session, which may be managed through *WinWRAP*, in which the roots of the filenames are entered and the files are opened. The program checks to confirm that the specified files do exist. If an input file is missing, a message to that effect appears on the monitor, and execution is terminated. An optional feature alerts the user if files with the output filenames already exist. The program requests verification from the user that these files are to be overwritten. The messages shown in Table 9.1 then appear on the monitor as the simulation is performed. Other similar messages related to specific modeling options appear only if those options are being used.

Table 9.1
SIM Trace Messages on Monitor

```

Root of input and output file names is entered
Root of hydrology file names is entered
Opening input file:  root.DAT
Opening output file: root.MSS
Reading the input data from file root.DAT
  ___ control points
  ___ water rights
  ___ reservoirs
Opening input file:  root.FLO
Opening input file:  root.EVA
Opening input file:  root.DIS
Opening input file:  root.OUT
Sorting water rights in priority order
Performing simulation for year _____
Performing simulation for year _____
  (repeated for each year)
Performing simulation for year _____

Input File:  root.DAT
Output File: root.OUT
Message File: root.MSS

***** Normal Completion of Program WRAP-SIM *****

Exit WRAP-SIM

```

SIM contains numerous error check routines that result in messages if erroneous or missing data are detected in the input files. *SIMD* includes all *SIM* checks plus additional checks for daily features. WRAP programs all have the same general format for reporting the detection of errors. An error message describing the problem is written to the message file. All error messages result in stopping program execution. The following message is written to the monitor.

```

*** Execution of SIM (or name of another program) terminated due to an input error.
*** See message file.

```

Progress in reading the input data is tracked by information written to the message file, which for *SIM* has the filename extension MSS, showing which records were successfully read. The MSS file trace will vary depending on the input records that are included in the dataset. If the entire DAT and DIS input files and the first year of *IN* and *EV* records are read without interruption, the pertinent messages shown in Table 9.3 plus usually others will be found in the message file. If model execution is prematurely terminated, the last notation in the input trace message listing provides the approximate location in the input files at which a problem occurred. The problem input file record will be after those records confirmed as having been read successfully. The error message will be written to the message file at the end of the trace.

JD Record ICHECK Options

Optional levels of input traces are specified by input variable *ICHECK* in field 4 of the *JD* record. The types of information copied to the message file with each value of *ICHECK* are shown in Table 9.2. The trace messages of Table 9.3 are printed regardless of *ICHECK* option.

Table 9.2
Information Recorded in Message File for Various Values of *ICHECK*

<i>ICHECK</i> = -1	All error and warning check routines are deactivated.
<i>ICHECK</i> = 0	Some error checks and most warning messages are deactivated.
<i>ICHECK</i> = 1	All error and warning routines are in effect.
<i>ICHECK</i> = 2	All <i>UC</i> and <i>RF</i> records are written as read.
<i>ICHECK</i> = 3	All <i>CP</i> records are written as read.
<i>ICHECK</i> = 4	All <i>WR</i> and <i>IF</i> records are written as read.
<i>ICHECK</i> = 5	All <i>SV</i> and <i>SA</i> records are written as read.
<i>ICHECK</i> = 6	All <i>IN</i> and <i>EV</i> records are written as read.
<i>ICHECK</i> = 7	All <i>FD</i> , <i>FC</i> , and <i>WP</i> records written as read.
<i>ICHECK</i> = 8	All dual simulation information.
<i>ICHECK</i> = 9	Most but not all error and many but not all warning checks are in effect.
<i>ICHECK</i> = 10	CRM trace written to MSS file for conditional reliability modeling.
<i>ICHECK</i> = 11	All <i>RU</i> records are written as read.
<i>ICHECK</i> = 12	Instream flow targets are recorded.
<i>ICHECK</i> = 13	Warning message alert that wrong-sign evap-precip was changed to zero.
<i>ICHECK</i> = 14	Wrong sign net evaporation-precipitation volume is not changed to zero.

An *ICHECK* of 0 or 1 is usually adopted. An *ICHECK* of 1 activates all error and warning checks. After a number of runs of *SIM* with a particular dataset repeatedly generating a long list of warning messages, the model-user may prefer to deactivate the warning messages by switching *ICHECK* to 0. The information generated by the *ICHECK* options is inserted within the MSS file trace messages shown in Table 9.3. An *ICHECK* value of from 2 to 7 results in the copying of a specified set of input records to the MSS file as they are read. If program execution is terminated, the error messages discussed in the next section will usually provide sufficient information to identify the problem without needing to resort to the *ICHECK* options 2–7. However, options 2 through 7 are sometimes useful in locating an erroneous input record. *ICHECK* option 8 writes information to the MSS file that is developed by routines activated by the *PX* record. *ICHECK* option 10 outlines the multiple CRM hydrologic sequences generated by the conditional reliability *CR* record described in Chapter 8.

For *ICHECK* options 2 through 10, most of the error checks for *ICHECK*=1 are in effect. However, most warning message checks and several of the error checks are in effect only if *ICHECK* is one. An *ICHECK* of 9 or 10 will deactivate many warning messages without affecting most error checks. Option 9 serves (1) to eliminate MSS file warning messages without deactivating most of the error checks and (2) to deactivate certain error checks.

Table 9.3
SIM Trace Messages Written to Message File

WRAP-SIM MESSAGE FILE

```

*** Starting to read file root.DAT.
*** JD record was read.
*** JO record was read.
*** Starting to read UC records.
*** Finished reading UC records.
*** Starting to read CP records.
*** Finished reading CP records.
*** Starting to read IF/WR records.
*** Finished reading IF/WR records.
*** Starting to read SV/SA records.
*** Finished reading SV/SA records.
*** Finished reading file root.DAT.
*** Starting to open remaining files.
*** Opened file root.FLO
*** Opened file root.EVA
*** Opened file root.DIS
*** Opened file root.OUT
*** Finished opening text files.
*** Starting to read FD/WP records from file root.DIS.
*** Finished reading ___ FD and ___ WP records.
*** Determined watershed parameters for ___ control points.
*** Finished ranking water rights in priority order.
*****
System components counted from input file:
___ control points (CP records)
___ primary control points (INMETHOD=1)
___ reservoirs
___ instream flow rights (IF records)
___ all water rights except IF rights (WR records)
___ system water rights
___ hydropower rights
___ sets of water use coefficients (UC records)
___ storage-area tables (SV/SA records)
___ storage-elevation tables (PV/PE records)
___ drought indices (DI records)
___ dual simulation rights
___ maximum upstream gaged cpts on FD records
*****
*** Beginning annual loop.
*** ___ IN and ___ EV records were read for the first year (___)
*** Flow distribution was performed for the first year.
*** Negative incremental flow adjustments were performed for the first year.
*** End of input data trace.

***** Normal Completion of Program WRAP-SIM *****

```

Program execution may be terminated due to a problem in an input record. Error messages normally provide sufficient information to locate the problem without the *ICHECK* options 2 through 7 input record reproduction routines noted in Table 9.2. However, *ICHECK* options 2 through 7 provide an additional tool to facilitate finding an erroneous record. *SIM* reads all the records in sequential order starting with the DAT file. The *ICHECK=1* trace is used to find the general location of the problem record based on where the trace stops with an error message. The program is then rerun with a different *ICHECK* value (options 2-7) to check which records in the groups noted in Table 9.2 are read and copied correctly.

With *ICHECK* options 2 through 7, the records are written to the MSS file immediately after each record is read. The records are copied to the MSS file almost verbatim as read, except most real numbers are written in a F8.0 Fortran format with zero digits to the right of the decimal point. If the program reads some but not all records of a particular record type, the problem will typically be associated with either the last record read and copied to the MSS file or more likely the next record in the input file. The types of records listed in Table 9.2 account for many but not all of the records in a *SIM* input set. *ICHECK=6* applies to *IN/EV* records stored in DAT, FLO/EVA, or DSS files but does not apply to an input file with filename extension HYD.

ICHECK option 8 relates to the *PX* record dual simulation option. *ICHECK=8* writes a list of rights with the dual option activated by the *PX* record and the array of initial simulation stream flow depletions for rights with *DUAL* options of 3 or 4.

Simulation results are written to the main output file (filename extension OUT) both as each individual water right is considered in the priority loop and at the end of each simulation month upon completion of the water rights priority loop. Thus, if execution is terminated after the input is read and the simulation computations begin, the computations can be tracked to approximately the point just before the computational problem. The OUT or SOU output files may also be useful in analyzing computational problems that do not terminate execution.

ICHECK Options that Affect *SIM* Simulation Results

The *ICHECK* options are designed primarily for generating information that is helpful in tracking the computations and detecting errors and potential issues, without affecting simulation results. However, the features noted below are designed to modify the actual *SIM* computations.

Several simulation features apply linear interpolation to input data tables such as those defined by *SV/SA* and *PV/PE* records. Warning messages are recorded in the MSS file if the maximum value in a table is exceeded. If a table is exceeded by more than 1.0% and *ICHECK=1*, *SIM* is terminated with an error message. Changing *ICHECK* to 9 results in the maximum value in the table being adopted with a warning message without terminating execution of *SIM*.

ICHECK options 13 and 14 deal with the issue of the computed net evaporation having the wrong sign. The net evaporation less precipitation depths input on *EV* records can be either positive or negative depending on whether evaporation versus precipitation rates are greatest in a particular month. The net evaporation-precipitation volumes computed in the iterative simulation algorithm should have the same sign as the depths. However, the computed volumes may have the wrong sign as reservoirs approach empty. *SIM* sets evaporation-precipitation volumes equal

to zero if the iterative algorithm results in final volumes with the wrong sign, unless *ICHECK* option 14 is activated. With *ICHECK*=14, the wrong-sign quantities are not changed to zero and a warning message is generated. With *ICHECK*=13, *SIM* follows its normal procedure of setting wrong-sign net evaporation volumes to zero, but generates a warning message. With *ICHECK* options other than 13 or 14, no warning message is generated for the wrong-sign quantities.

Error and Warning Messages

All of the WRAP programs have a similar system for managing error and warning checks. Error messages are always accompanied by automatic termination of program execution, but execution continues with warning messages. Various error checks are performed as the input files are read and the simulation computations are performed. If data are missing or in the wrong format or inconsistencies are detected, program execution is stopped and an error message is written to the message MSS file. Warning messages identify potential problems and are also written to the message file, but program execution is not terminated. Warning routines simply write messages without affecting the simulation. Thus, the message file should be checked for warning messages even if the program runs to a normal completion.

Error messages in all of the WRAP programs are written similarly. First an individualized statement written to the message file provides information regarding the particular type of error detected. Then a standard message is written to both the monitor and MSS file followed by termination of program execution. The Fortran input/output status specifier *IOSTAT* is included in essentially all of the read statements of all the programs. Numerous other specific error check algorithms are coded into various data input and computational routines.

If violation of a Fortran rule is indicated by the *IOSTAT* variable in a read statement, messages are written to the monitor and MSS file along with the program being terminated. *IOSTAT* errors result in variations of the following message being written to the monitor.

```
*** Execution of SIM terminated due to an input error.  
*** IOSTAT status variable (error code) = ____  
*** ____ record contains data in wrong format.  
*** End of file was reached without finding data record.  
*** End of ____ record was reached without finding data.  
*** See message file.
```

The first and last line of the message are displayed on the monitor with any error. The second and one of the three or similar lines are added for *IOSTAT* errors. When *IOSTAT* errors occur in reading the DAT file, the following message may be written to the message file along with the last two records read.

```
ERROR: Fortran IOSTAT error occurred reading an input record with identifier CD of ____  
IOSTAT status variable = ____  
The first 82 characters of each of the last two records read are as follows:
```

The monitor and MSS file messages indicate the value for the *IOSTAT* variable as defined within the Fortran language compiler. A negative one (-1) means the end of file was reached without finding the data record. A -2 indicates the end of the record was reached without finding

the data. A positive integer refers to Fortran error condition messages provided by the compiler. The most common *IOSTAT* values are 61 and 64, meaning input data is in the wrong format, such as a letter in a real or integer numeric field or a decimal in an integer field.

Many other error checking routines are coded into *SIM* with error or warning messages that are written to the message file. Error messages are accompanied by termination of model execution. Warning messages do not stop the model or in any way affect the simulation. Many of the error and warning messages are listed in Tables 9.4 and 9.5. Numerous other messages not included in Tables 9.4 and 9.5 have formats similar to those shown.

The checks associated with error and warning messages take various forms. For example, essentially any identifier connecting records are checked to verify that they are on the other record. The control point identifiers on *WR*, *IF*, *CI*, *SO*, *FS*, *TO*, *ZZ*, *FD*, and *WP* records are checked to ascertain that they match identifiers on *CP* records. Likewise, water use identifiers on *WR* records are matched against those on the *UC* records. Reservoir identifiers on *SV*, *PV*, *MS*, *EA*, and *DI* records are checked to ascertain that the reservoirs have been entered on *WS* reservoirs. Upstream control points on *FD* records must actually be upstream of the specified control point as defined by *CP* records. Checks are made on certain numerical data entries to ascertain that the numbers fall within appropriate ranges. Some checks involve detecting missing records or data. Other types of checks are illustrated as well in Tables 9.4 and 9.5. *HYD* provides additional checks of *IN* and *EV* records discussed in the *HYD* section of this chapter.

Since error and warning messages are written as problems are detected along with the trace messages, their approximate originating location in the model is evident. All error and warning checks are in effect for *ICHECK* (*JD* record field 4) option 1. If *ICHECK* option 1 is not selected, most warning checks and some of the error checks are not activated.

Table 9.4
SIM Error Messages

Written to MSS File from main program while performing simulation

ERROR: CP output written for ___ control points but expecting ___
ERROR: TOTARGET of ___ on TO record is not valid. Water right: _____
ERROR: TOTARGET=10 can not be combined with TOCOMB=LIM. Water right: _____
ERROR: The ID of ___ for reservoir _____ from BES file should be _____
ERROR: Reservoir _____ from EA record could not be matched with WS record reservoir identifiers.
ERROR: Reservoir _____ could not be matched with EA record reservoir.
ERROR: Reached end of file without finding ED record.

Written to MSS File from Subroutine READDAT which reads DAT File

ERROR: Read inappropriate record with CD of ___
ERROR: Missing JD record.
ERROR: Number of years on JD record field 2 must be at least one.
ERROR: ADJINC of ___ and NEGINC of ___ on JD record are not compatible.
ERROR: ADJINC of ___ on JD record is not valid.
ERROR: EPADJ of ___ in JD field 10 is not valid.
ERROR: IDSET of ___ in JD field 12 is not valid.
ERROR: INEV of ___ on JO record is not valid.

Table 9.4 (Continued)
SIM Error Messages

ERROR: SYSOUT of ___ on JO record is not valid.
 ERROR: PASS2 of ___ on JO record is not valid.
 ERROR: BES = ___ in JO field 5 is not valid.
 ERROR: BRS = ___ in JO field 6 is not valid.
 ERROR: CR1 on CR record must be greater than zero.
 ERROR: CR2 on CR record must be a month between 1 and 12. Read CR2 of ___
 ERROR: On CR record, CR1 of ___ is invalid with nonzero CR2 of ___
 ERROR: The FY record water right identifier did not match any water right on WR records.
 ERROR: FYIN(2) and FYIN(3) on FY record must be positive nonzero numbers. Read: _____
 ERROR: The incremental decreases on FY record must each be less than previous level. Read: _____
 ERROR: The FY record water right identifier matched ___ water rights on WR records which exceeds
 the dimension limit of 100.
 ERROR: WO record missing. Read CD = _____
 ERROR: GO record missing. Read CD = _____
 ERROR: RO record missing. Read CD = _____
 ERROR: CO record missing. Read CD = _____
 ERROR: Missing WO, GO, RO, or CO record.
 ERROR: Use identifier ___ from UP record matches no identifier on UC records.
 ERROR: Read CD of ___ when expecting CP records.
 ERROR: Read inappropriate CD of ___ after or within CP records.
 ERROR: Missing (UC, CP) record. Read CD of _____
 ERROR: Control point ___ has an invalid INMETHOD of ___
 ERROR: Downstream control point identifier [CPID(cp,2)] ___ on CP record for ___ matches no CPID(cp,1).
 ERROR: Identifier ___ assigned to both control points ___ and ___
 ERROR: Control point identifier ___ from (CI,WR,IF,SO,FS,PX) record ___ matches no control point identifier
 on CP records.
 ERROR: Water use identifier ___ from WR or IF record matches no identifier on UC records.
 ERROR: Invalid Type of ___ in WR field 6 for water right _____
 ERROR: IFMETH of ___ is not valid. IF right _____
 ERROR: Return flow identifier ___ from WR record ___ matches no identifier on the RF records.
 ERROR: Invalid RFMETH of ___ in WR field 7 for water right _____
 ERROR: Water rights ___ and ___ associated with reservoir ___ do not have
 cumulative storage capacities with respect to priorities.
 ERROR: Subroutine READDAT set MAXSWR at ___ but tried to read WR/IF records for at least ___ system rights,
 indicating a problem with hydropower or multireservoir rights.
 ERROR: IFMETH = 3 or 4 but there is no reservoir (WS record) for IF right _____
 ERROR: BU of ___ on BU record is not valid. Right _____
 ERROR: BUWRID of _____ for right _____ matches no WRID on WR or ID records.
 ERROR: BUG of _____ for right _____ matches no WRIDS on WR or ID records.
 ERROR: SO record field 6 is limited to blank or BACKUP, BFIRST, or RETURN. Read: _____
 ERROR: ISHT of ___ in SO record field 9 is invalid.
 ERROR: TO record field 10 is limited to blank or CONT. Read: _____
 ERROR: TOTARGET of ___ is not valid. Water right _____
 ERROR: TOTARGET=10 combined with TOCOMB=LIM is not valid. Water right: _____
 ERROR: Reservoir identifier is missing from TO record field 8 for water right _____.
 ERROR: Water right identifier is missing from TO record field 9 for water right _____.
 ERROR: Reservoir ___ entered in field 8 of a TO record is not on any WS record.
 ERROR: Water right ___ entered in field 9 of a TO record is not on any WR record.
 ERROR: TOCOMB of ___ on TO record is not valid. Water right: _____
 ERROR: Read CD of ___ instead of TO for a continuation TO record for water right: _____
 ERROR: Upper bound of ___ is less than lower bound of ___ on FS record. Right _____

Table 9.4 (Continued)
SIM Error Messages

ERROR: Invalid FSV of ___ in FS field 2 for water right _____
 ERROR: FS record multiplier factors are both blank or zero for right _____
 ERROR: FS record field 9 is not used without an ending month in field 10. Right: _____
 ERROR: FS record field 10 is not used without a beginning month in field 9. Right: _____
 ERROR: TS record is not valid for year ___ for water right _____ CD, TSYR1, TSYR2 read as follows: _____
 ERROR: ___ read for TSL from TS record is not valid. Water right: _____
 ERROR: ___ for K is TSR record field 2 is not valid. Water right: _____.
 ERROR: Invalid XP option of ___ on PX record field 5 for water right _____
 ERROR: Invalid XPR option of ___ on PX record field 6 for water right _____
 ERROR: PX record priority of ___ is less than WR record priority of ___ for water right _____
 ERROR: DUAL is 5 for water right _____ but there is no preceding dual option 4 right.
 ERROR: DUAL of ___ is invalid for water right _____
 ERROR: Invalid XCP option of ___ on PX record field 3 for water right _____
 ERROR: XCPID missing in PX record field 4 for water right _____
 ERROR: The number of system reservoirs (WS records) exceeds MAXSYS of ___ for right _____
 ERROR: Reservoir _____ on (MS,DI,EA) record is not on any WS record.
 ERROR: WS record is not compatible with TQ/TE record for reservoir _____
 ERROR: Missing (SV/SA,PV/PE,TQ/TE) record. Read CD of _____
 ERROR: Missing or duplicate reservoir ID found while reading (SV/SA, PV/PE,TQ/TE) records.
 ERROR: The drought index DINDEX from the WR/IF record is ___ for right ___ but there are only ___ DI records.
 ERROR: EMPTY of ___ on DI record is not valid.
 ERROR: Reservoir _____ on DI record is not on any WS record.
 ERROR: Number of reservoirs on DI record must be 1 to 12 or all (-1).
 ERROR: Read CD of ___ when expecting EF.
 ERROR: Reservoir _____ on EA record is not on any WS record.
 ERROR: Reservoir _____ on EA record has EAR of ___ on WS record.
 ERROR: Reservoir _____ has EAR of ___ on WS record but has no EA record.
 ERROR: NEAF of ___ in EA field 3 is invalid.
 ERROR: EF record is used only if NEAF is 3 or 4 in EA field 3.
 ERROR: EAO is EF field 2 should be between 0 and 4. Read ___
 ERROR: No SV/SA records are assigned to reservoir _____ on EA record.
 ERROR: EAO of 3 or 4 in EF field 2 is valid only for NEAF of 4 in EA field 3.
 ERROR: CD of ___ is used only in SIMD, not SIM.
 ERROR: Number of control points and water rights must be at least one.
 ERROR: Inappropriately reached end-of-file while reading DAT file. The last CD read was _____
 ERROR: The following invalid record identifier (CD in field 1) was read: _____

Written to MSS File from Subroutines INEV1 and INEV2 which read IN and EV records

ERROR: In reading (IN,EV) records, read control point ID of ___ when expecting _____
 ERROR: In reading (IN,EV) records for control point _____ for year _____ read FYR of _____
 ERROR: IN records were read for CP ___ but INMETHOD = ___ on CP record.
 ERROR: EV records were read for CP ___ but CPEV = ___ on CP record.
 ERROR: (CPIN, CPEV) in field (7, 8) of CP record for _____ was not found.

Written to MSS File from Subroutine INEVYR which reads IN and EV records

ERROR: In reading first IN record for first year _____ read NYR of ___ and INLYR of _____
 ERROR: In reading first IN record for first year, read CD of _____ instead of IN.
 ERROR: In reading IN records for control point _____ for year _____ read INLYR of _____
 ERROR: In reading EV records for control point _____ for year _____ read EVLYR of _____
 ERROR: In reading (IN,EV) records for year ___ a CD of ___ was read.
 ERROR: (IN,EV) record was not found for year ___ for control point identifier _____
 ERROR: (CPIN, CPEV) in field (7, 8) of CP record for _____ was not found.

Table 9.4 (Continued)
SIM Error Messages

Written to MSS File from Subroutine IACNP which reads DIS File

- ERROR: Found CD of ___ in the DIS file, when expecting FD, FC, or WP record.
 ERROR: _____ from field 2 of FD record ___ matches no control point identifier on CP records.
 ERROR: Upstream gage identifier _____ from FD record ___ matches no control point identifier on CP records.
 ERROR: _____ on the ___ WP record matches no control point identifier on CP records.
 ERROR: On FD record for _____ the upstream gage _____ is not upstream of the downstream gage _____
 ERROR: NG is -1 on FD record for _____ but the source gage _____ is not upstream of the ungaged control point.
 ERROR: Upstream control point UGID(I) of _____ is repeated twice on FD record for CP _____
 ERROR: The downstream gaged source control point associated with ungaged CP _____ is missing or not specified on a FD record.
 ERROR: The drainage area for CP _____ is missing, zero, or negative: _____
 ERROR: The incremental drainage area for CP _____ is zero or negative: _____

Written to MSS File from Subroutine FLDIST which performs flow distribution computations

- ERROR: NRCS CN method can not be applied for zero or negative drainage area for CP _____
 ERROR: Gaged CP _____ is not downstream of ungaged CP _____ as required by INMETHOD (6,8)

Written to MSS File from Subroutine LINEAR which performs linear interpolation

- ERROR: Table number must be a positive integer. Table number of ___ associated with water right _____
 Stopped in linear interpolation subroutine.

Written to MSS File from Subroutine DROUGHT which develops drought index

- ERROR: Interpolation of drought index ___ is out of range.

Written to MSS File from Subroutine FLOWADJ which reads FAD file and adds FA record flows

- ERROR: Control point identifier ___ in FAD file matches no control point identifier on CP records.
 ERROR: Computations terminated due to error in FAD file. Error occurred at control point ___ during year ___

Table 9.5
SIM Warning Messages

Written to MSS File from main program while performing simulation

- WARNING: The beginning of simulation storage specified for reservoir _____ exceeds its capacity.
 The initial storage is set at the capacity.
 WARNING: The BES beginning storage of _____ for reservoir _____ exceeds its capacity of _____
 WARNING: An HRR file has been created but no system water rights are specified.
 WARNING: The TOCOMB=DIV option for right _____ involved dividing by zero and thus was skipped.
 WARNING: Evaporation volume has wrong sign. _____
 WARNING: PASS2 on JO record is 2, but there are no IF records.
 WARNING: A -1.0 in output file indicates format limit exceeded. Year: _____ CP: _____
 WARNING: JD field 4 ICHECK is 8 but there are no dual simulation rights (PX record).

Written to MSS File from Subroutine READDAT which reads the DAT File

- WARNING: The water right type WRNUM(wr,5) for an IF record right is automatically set at 2 meaning reservoir storage is not refilled. A type of ___ entered on the IF record was changed to 2 for IF right: _____
 WARNING: A next-month return flow option is used with PX record field 6 option for water right _____
 WARNING: A non-zero XPR does not pertain to XP option 1 (PX record fields 6 and 7). water right _____
 WARNING: The format of the WS record used with water right _____ has been replaced with the new WS/HP record format but still works.

Table 9.5 (Continued)
SIM Warning Messages

-
- WARNING: Read HP record but type is ___ for right _____
- WARNING: Energy limit of ___ in HP record field 7 is less than WR record target of ___ for water right _____
- WARNING: No storage capacity on WS record for reservoir ___ right _____
- WARNING: Inactive storage of ___ exceeds capacity of ___ for water right _____
- WARNING: Beginning storage of ___ exceeds capacity of ___ for water right _____
- WARNING: EA record should be used only with type 1 rights. _____ is type ___
- WARNING: An OR record may be inappropriate for water right _____ OR records are not used with single-reservoir type 1 or hydropower rights or with the first reservoir for these type rights with multiple reservoirs since storage is refilled in the first reservoir.
- WARNING: Water rights _____ and _____ at reservoir ___ have storage capacities that are inconsistent with priorities. A junior right can not have a smaller cumulative storage capacity than a senior right at the same reservoir.
- WARNING: Control point ID of a reservoir is missing for multiple-reservoir system right _____
- WARNING: The water right and reservoir normally should be at the same control point for a type 1 right.
Reservoir: _____ Water right: _____
- WARNING: There is a reservoir (WS record) but IFMETH is not 3 or 4 for IF right _____
- WARNING: SV/SA records are provided but not assigned to a reservoir.
- WARNING: PV/PE records are provided but not assigned to a reservoir.
- WARNING: Missing storage-area or elevation table.
- WARNING: TQ/QE records are provided, but not assigned to a reservoir. Reservoir ID = _____
- WARNING: Incorrect NDI identifier in field 2 of DI record.
- WARNING: EAL on EF record should be between 0.0 and 1.0. Read _____
- WARNING: EF record EAF of ___ for last reservoir listed on EA record is not used.
- WARNING: Incorrect NEA identifier in field 2 of EA record.
- WARNING: XPR is ___ on PX record for run-of-river water right: _____
- WARNING: ___ on CO record is not on any CP record.
- WARNING: ___ on WO record is not on any WR record.
- WARNING: ___ on GO record is not on any WR record.
- WARNING: ___ on RO record is not on any WS record.
- WARNING: No WR/IF records have drought indices but there are ___ DI records.
- WARNING: ___ rights have drought indices ranging from ___ to ___ and MAXDI is _____
- WARNING: Inconsistency in water right counts. NWRTS is ___ and MAXWR is _____
- WARNING: Inconsistency in control point counts. NCPTS is ___ and MAXCP is _____
- WARNING: Inconsistency in reservoir counts. NRES is ___ and MAXWS is _____
- WARNING: Inconsistency in SV/SA table counts. NTABLE is ___ and MAXTAB is _____
- WARNING: Inconsistency in PV/PE table counts. NTABLE is ___ and MAXTAB is _____
- WARNING: A HRR file is activated, but there are no system water rights.

Written to MSS File from Subroutine FLOWADJ which reads the FAD File

- WARNING: Year ___ not found in FAD file.

Written to MSS File from Subroutine LINEAR which performs linear interpolation

- WARNING: Interpolation routine exceeded range of table _____
max X = _____ given X = _____ Y = _____ max Y = _____

Written to MSS File from Subroutines INEVYR, INEV1, and INEV2 which read IN and EV records

- WARNING: Inflows are not provided for control point _____. Zero flows are assumed.
- WARNING: CPIN repeats IN records from a CP that has no IN records.
Control points CPID and CPIN are _____ and _____
- WARNING: For CP _____ INMETHOD= _____ on CP record but there are no IN records.

Table 9.5 (Continued)
SIM Warning Messages

- WARNING: CPEV repeats EV records from a CP that has no EV records.
Control points CPID and CPEV are ___ and ____.
- WARNING: Net evaporation-precipitation depths are not provided for control point ____
Zero net evaporation-precipitation depths are assumed.
- WARNING: For CP ___ CPEV is blank on CP record but there are no EV records.

Written to MSS File from Subroutine RESCAL which computes reservoir evaporation and storage

- WARNING: End-of-month storage did not converge to within 0.1 acre-feet in 50 iterations of
iterative evaporation computations for water right _____.
Reservoir: ___ CP: ___ Year: ___ Month: ___ Final Evap: ___
BPSTOR: ___ EPSTOR: ___ 50th EPSTOR Adopted: ___

Written to MSS File from Subroutine RELEASE which computes multiple-reservoir system releases

- WARNING: Unable to deliver releases to water right ___ from reservoir ___ due to channel
loss factor of 1.0

Written to MSS File from Subroutine POWER which performs hydropower computations

- WARNING: Energy produced did not converge to within 0.01 percent of target in 50 iterations of
iterative hydropower computations for water right _____.
Reservoir: ___ Year: ___ Month: ___ Energy target: ___
BPSTOR: ___ 49th POWPRO ___ 50th POWPRO adopted: ___

Written to MSS File from Subroutines IACNP or FLDIST which read DIS file and distribute flows

- WARNING: The incremental CN and/or mean precipitation MP is negative for gaged ___ or ungaged ___
gaged CN, ungaged CN, gaged MP, ungaged MP = ___ ___ ___ ___
- WARNING: Convergence criterion of 0.5% was not met for flow distribution option 8 after 100 iterations
at ungaged CP ___ for year ___, month ___. Last flow computed of ___ was adopted.
- WARNING: Evap-precip adjustment at control point ___ for EWA(cp) of ___ for year ___, month ___
Runoff Adjustment (feet) = _____
- WARNING: The drainage area for CP ___ is missing, zero, or negative.
- WARNING: The CN of CP ___ violates the CN bounds: ___ ___

Written to MSS File from Subroutine BISECT which solves CN equation for Subroutine FLDIST

- WARNING: Subroutine BISECT stopped at 100 iterations in solving the NRCS CN equation for P.
-

Locating Errors in the SIM Output File

With a completed simulation, *SIM* results organized with *TABLES* can be examined in great detail with the output data organized in a variety of tabulations. The *SIM* output SOU file provides an easy-to-read format but does not track the computational sequence as directly as the OUT file. If *SIM* terminates prior to completion, the OUT file still contains all results computed up to program termination. Essentially all numbers generated by *SIM* can be written to the OUT and scrutinized. The content and format of the records in the OUT file are outlined in Tables 5.1–5.5 of Chapter 5. The *SIM* simulation computations are outlined in Figure 2.2 in Chapter 2. Water right output records are written to the OUT file in sequence as each water right is considered in priority order. Control point and reservoir/hydropower output records are written to the OUT file for each month at the end of the water right priority loop.

The following discussion addresses the situation in which *TABLES* will not read an OUT file from an apparently successful execution of *SIM* even though the *TABLES* input file is completely correct. This situation should be encountered by model users seldom, if ever. After a *SIM* input dataset has been successfully debugged, irregularities in the *SIM* output OUT file should be rare.

Program *TABLES* includes a routine activated by the TEST record that performs a series of checks on a *SIM* output file. The TEST option in *TABLES* is designed for use in the unusual situation in which *TABLES* can not read an OUT file from a successful *SIM* simulation. The following tests are performed. The tests are applicable only to an OUT file created as a text file rather than as the optional unformatted binary file specified by *JD* record field 7.

TABLES reads the first record of the OUT file, and an error message is written to the TMS message file if irregularities are encountered. The problem will most likely be that *TABLES* is expecting a text file but the OUT file is not an ordinary text file. The only type of text file that can be read by *TABLES* is an ordinary text file with no enhancements. The Fortran code in *SIM* always creates a text file in the correct format. However, if the model-user reads the OUT text file with WordPad or some other editor and inadvertently saves the file in another format that adds formatting characters, *TABLES* will not be able to read the file. The TEST routine will detect the problem.

Most of the data in an OUT file are numbers. The TEST routine checks whether letters or other characters appear in the fields that should be numbers. Error messages are written to the TMS file if improper characters are found. The most likely problem is the occurrence of either *NaN* or ******* in the OUT file. The *SIM* code includes checks to prevent these situations from occurring. The *TABLES* TEST routine provides another backup check.

The term *NaN*, meaning *not a number*, is written by a Fortran program when an arithmetic operation is not defined. The undefined operation is usually dividing by zero. A number can not be divided by zero. The *SIM* code is written with checks to prevent divisions in which the denominator could be zero. However, if the safeguards fail, a *NaN* could be written to the OUT file and detected by the *TABLES* TEST routine.

Format specifications for the variables written to the OUT file are described in Chapter 5 of the *Reference Manual*. If a computed number has more digits than is allowed by a Fortran format statement, the number is replaced by the program with asterisks (*******) in the output file. *SIM* includes safeguards to prevent this situation along with warning messages. However, the *TABLES* TEST routine will detect asterisks if they occur.

The TEST routine also checks that all water right output records in the OUT file are in the correct chronological order by year and month. For control point and reservoir output records, the control point and reservoir identifiers are read for the first month and checked for consistency in all subsequent months. Thus, an incorrect ordering of records or incorrect number of records will be detected. *SIM* should always write the correct number of records in the proper sequence. However, this test feature provides yet another check in exploring a corrupted file or occurrence of a strange unexplained problem.

Locating Errors in TABLES Input Data

Instructions for applying the WRAP program *TABLES* are provided by Chapter 5 of the *Users Manual*. *TABLES* is very modular. Operations are controlled by records entered in an input file with filename extension TIN. *TABLES* reads one record of the TIN input file, performs the specified operations, records the results, and then proceeds to the next record in the TIN file. Trace messages are written to the message TMS file as each TIN file input record is read. Thus, if an input problem occurs, the input record causing the problem is evident.

All of the WRAP programs have the same basic system for recording error and warning messages on the monitor and in the message file. *TABLES* is the same as *SIM* and *HYD* in this regard. Checks are embedded in various routines in *TABLES*. Program execution is terminated with error messages but is not terminated with warning messages.

Locating Errors in HYD Input Data

WRAP-HYD documented by the *Hydrology Manual* contains features similar to those of *WRAP-SIM* to help detect missing records or inconsistencies and locate erroneous records that cause program execution to terminate due to illegal computer operations. These features do not pertain to those situations in which reasonable but incorrect data are input in the right format.

Tracking Program Progress

Tracing the progress of reading input records and performing computations up to program termination may be useful in locating the input record causing the problem. The following *HYD* features trace the progress of the simulation.

HYD execution begins with an interactive session in which the user supplies the root of the input and output filenames, and the files are opened. The program checks whether the specified files exist, writes a message to the monitor if an input file is missing, and allows the user to confirm overwriting of existing output files. The messages shown in Table 9.6 then appear on the monitor as various tasks are performed.

Progress is tracked in more detail by notes the program writes to the message file, which has the filename extension HMS. If program execution is terminated prior to completion the specified tasks, the trace messages help locate the input record causing the problem. Optional levels of input data traces are specified by input variable *ICHECK* in field 4 of the *JC* record. The basic trace (*ICHECK* \geq 0) consists of printing the messages shown in Table 9.7 to the HMS file. Only those messages associated with options included in the *HYD* application will be written to the message file. If model execution is prematurely terminated, the last message provides the approximate location in the input files at which a problem occurred.

Additional information noted in Table 9.7 may also be written to the message file as specified by *ICHECK* in field 4 of the *JC* record. The *ICHECK* = 1 trace shown in Table 9.7 is used to find the general location of the problem record based on where the trace stops. The program is then rerun with a different *ICHECK* value to check which records in the groups noted in Table 9.7 are read and copied correctly.

Table 9.6
HYD Trace Displayed on Monitor

```

Reading the input data from file_____.HIN
*****
HIN file record counts:
  ___ control points
  ___ control points with IN records
  ___ OUT input file OI records
  ___ evap-precip rate adjustment EP records
  ___ representative year AN records
  ___ adjustment specification AS records
  ___ adjustment equation EQ records
*****
Reading the IN/EV records
Developing EV records as specified by EP records
Adjusting flows as specified by AS records
Distributing flows from gaged to ungaged control points (FD records)
Writing IN and/or EV records to output file(s)
***** Normal Completion of Program WRAP-HYD *****

```

ICHECK options 3 through 7 should seldom if ever be required, but provide a backup approach for otherwise hard-to-find input errors. For *ICHECK* options 3 through 7, the records noted in Table 9.7 are written to the HMS file immediately after each record is read. The records are copied to the HMS file almost verbatim as read, except most real numbers are written in a F8.0 Fortran format with zero digits to the right of the decimal point. Blank fields read as zeros are output as zeros. If the program reads some but not all records of a particular record type, the problem will typically be associated with either the last record read and copied to the HMS file or more likely the next record in the input file.

Table 9.7
Trace Information Copied to Message File for Various Values of ICHECK

ICHECK = 0	Messages shown in Table 9.8; most error detection routines in effect
ICHECK = 1	Messages shown in Table 9.8; all error detection routines in effect
ICHECK = 2	Messages shown in Table 9.8; IN and EV record check
ICHECK = 3	Messages shown in Table 9.8 plus all <i>CP</i> records as read
ICHECK = 4	Messages shown in Table 9.8 plus all <i>AS</i> records as read
ICHECK = 5	Messages shown in Table 9.8 plus all <i>SV</i> and <i>SA</i> records as read
ICHECK = 6	Messages shown in Table 9.8 plus all <i>IN</i> and <i>EV</i> records as read
ICHECK = 7	Messages shown in Table 9.8 plus all <i>FD</i> , <i>FC</i> , and <i>WP</i> records as read

Table 9.8
HYD Trace Messages Written to HMS File

```

*** Starting to read file _____.HIN.
*** JC record was read.
*** Starting to read CP records.
*** Finished reading CP records.
*** Starting to read CI records.
*** Finished reading CI records.
*** Starting to read SV/SA records.
*** Finished reading SV/SA records.
*** Counting EP records. (They will be reread later.)
*** Finished reading file _____.HIN.
*****
Number of CP, SV/SA, and EP records read from HIN file.
    ____ control point CP records
    ____ control points with IN records
    ____ storage-area table SV/SA records
    ____ evap-precip rate adjustment EP records
*****
*** Starting ICHECK=2 check of IN records.
*** Finished ICHECK=2 check of ____ IN records.
*** Starting ICHECK=2 check of EV records.
*** Finished ICHECK=2 check of ____ EV records.
*** Starting to read IN/EV records.
*** Rearranging first year inflows and multiplying by factors on CP records.
*** Reading first year evap-precip rates.
*** Rearranging first year evap and multiplying by factors on CP records.
*** Finished reading IN/EV records.
*** Starting to read IN records from INF file in optional format [JC(1)=2].
*** Reordering IN records and multiplying by factors on CP records.
*** Starting to read EV records from EVA file in optional format [JC(1)=2].
*** Reordering EV records and multiplying by factors on CP records.
*** Finished reading IN/EV records.
*** Starting to read EP records.
*** Finished developing EV records as specified by EP records.
*** Starting to adjust flows as specified by AS and/or EQ records.
*** Finished adjusting flows as specified by AS and/or EQ records.
*** Starting negative incremental flow routine (ADJINC/NEGINC on JC record).
*** Finished negative incremental flow routine.
*** Starting to read flow distribution DIS file.
*** Finished reading flow distribution DIS file.
*** Starting flow distribution computations.
*** Finished flow distribution computations.
*** Starting to write IN and/or EV records to FLO/EVA files.

***** Normal Completion of Program WRAP-HYD *****

```

ICHECK Option 2 IN and EV Record Checks

SIM and HYD performed similar checks when reading inflow *IN* and evaporation *EV* records with ICHECK option 1 selected in *JD* or *JC* record field 4. ICHECK option 2 in *HYD* activates a routine that performs a series of checks of *IN* and *EV* records that includes several extra checks in addition to those performed with ICHECK option 1. The *HYD* ICHECK option 2 checks are performed on INF and EVA files that may serve as input files for either *HYD* or *SIM*. The *ICHECK=2* routine is applicable to INF and EVA files but not a *HYD* file. Checks performed for ICHECK option 2 result in the normal error messages for Fortran IOSTAT errors and result in warning messages written to the HMS file if the following irregularities are detected.

- Control point identifiers on *IN* and *EV* records must match identifiers on *CP* records.
- *IN* records should correspond to INMETHOD(cp) option 1 on the *CP* records.
- *EV* records should correspond to a blank CPEV(cp) on the *CP* records.
- Years on *IN* and *EV* records should fall within the period-of-analysis defined by JC(1) and JC(2).
- Years on *IN* and *EV* records should increase sequentially in chronological order.
- The number of *IN* and *EV* records should be consistent for each year and each control point. The total numbers of *IN* and *EV* records are recorded.

The routine reads the control point identifiers entered in field 2 of the *IN* and *EV* records and matches them against those on the *CP* records. The following warning message is written to the HMS file for each *IN* or *EV* record that does not match a *CP* record.

WARNING: Control point ___ on (IN or EV) record matches no identifier on CP records.

If *IN* records are provided, the variable *INMETHOD* in field 6 of the *CP* record should be zero or one. If this is not the case, the following message is written.

WARNING: INMETHOD is ___ on CP record for control point _____ on IN record.

If *EV* records are provided, field 8 of the *CP* record (*CPEV*) should be blank. If this is not the case, the following message is written.

WARNING: CPEV is _____ on CP record for control point _____ on EV record.

Similar warning messages are activated by other ICHECK=2 checks.

Error and Warning Messages

HYD contains a variety of other error and warning checks that are applied with the other ICHECK options in addition to the ICHECK option 2 checks noted above. Most are performed as the input files are read. If data are missing or in the wrong format, program execution is stopped and an error message is written. Warning messages identify potential problems, but program execution is not terminated. Error and warning messages are written to the HMS file. *HYD* and *SIM* both generate two types of error messages:

1. The Fortran input/output status specifier *IOSTAT* is included in most of the read statements.
2. Many other specific error check algorithms are coded into the various routines. Many of the *SIM* error messages and other similar messages are incorporated in *HYD*.

If violation of a Fortran rule is indicated by the *IOSTAT* variable in a read statement, the following complete message is written to the message file, the first two lines of the message are displayed on the monitor, and execution is terminated.

ERROR: Fortran IOSTAT error occurred reading an input record with identifier CD of ____
 IOSTAT status variable = ____
 The first 80 characters of each of the last two records read are as follows:

The last two records read from the input file prior to termination of the program are written following this message. The message indicates the value for the *IOSTAT* variable as defined within the Fortran language compiler. A negative one (-1) means the end of file was reached without finding the data record. A -2 indicates the end of the record was reached without finding the data. A positive integer refers to error condition messages provided by the compiler. The most common value for the *IOSTAT* variable is 64, which means input data is in the wrong format, such as a letter in a real or integer numeric field or a decimal in an integer field. A 39 indicates a problem with a read statement, but no information regarding the problem is available.

Other *HYD* warning and error messages are listed in Tables 9.9 and 9.10. Subroutines *INFEV1*, *INEV2*, *INEVYR*, *IACNP*, *FLDIST*, and *BISECT* are essentially the same in *HYD* and *SIM* and have the same error and warning messages. The *SIM* messages identified with these shared subroutines in Tables 9.4 and 9.5 are not repeated in Tables 9.9 and 9.10, which show many of the additional *HYD* messages that are not in *SIM*.

Table 9.9
 HYD Warning Messages

WARNING: ICHECK=2 option specified on JC record is invalid without FLO and EVA files.
 WARNING: No output is written since INEV(1)=5 in field 12 of first CP record.
 WARNING: No input is specified on JC record.
 WARNING: No output file is specified in JC record.
 WARNING: First year in OUT file does not match YRST on JC record: ____ ____
 WARNING: Number of years in OUT file does not match NYRS on JC record: ____ ____
 WARNING: Control point identifier ____ in OUT file matches no CP record in HIN file.
 WARNING: Control point identifier ____ on CP record is not found in OUT file.
 WARNING: Reservoir identifier ____ in OUT file matches no reservoir in HIN file though JC(2)=7.)
 WARNING: Reservoir identifier ____ on CP record is not found on reservoir records in OUT file though JC(2)=7.
 WARNING: Inflows are not provided for control point ____ . Zero flows are assumed.
 WARNING: Net evaporation-precipitation depths are not provided for control point ____ zero net
 evaporation-precipitation depths are assumed.
 WARNING: Read a FA record when Abs(AS(3)) is greater than 1.
 WARNING: Read a RS record when AS(3) is not 2.

Table 9.10
HYD Error Messages

Written to HMS File from Subroutine READHIN

ERROR: Missing JC record.
 ERROR: Number of years on JC record must be at least one.
 ERROR: JC(1,2,3,4,5,6) of ___ on JC record is not valid.
 ERROR: ADJINC of ___ and NEGINC of ___ on JC record are not compatible.
 ERROR: ADJINC of ___ on JC record is not valid.
 ERROR: EPDADJ of ___ in JC field 13 is not valid.
 ERROR: Control point ___ has an invalid INEV of ___ (CP record field 12)
 ERROR: Following CP record for control point ___ a record with CD of ___ was read instead of MF.
 ERROR: Missing CP record. Read CD of ___
 ERROR: Control point ___ has an invalid INMETHOD of ___
 ERROR: Downstream control point identifier [CPID(cp,2)] ___ on CP record for ___ matches no CPID(cp,1).
 ERROR: Identifier ___ is assigned to both control points ___ and ___
 ERROR: (CPIN(cp),CPEV(cp)) of ___ on CP record for control point ___ matches no CPID(cp,1) identifier.
 ERROR: Control point identifier ___ from CI record ___ matches no control point identifier on CP records.
 ERROR: Missing SV/SA record. Read CD of ___
 ERROR: Missing or duplicate reservoir ID found while reading SV/SA records.
 ERROR: VAR of ___ on OI record is not valid.
 ERROR: OG of ___ on OI record is not valid.
 ERROR: OID of ___ on OI record is on no CP record.
 ERROR: Read CD of ___ instead of supplemental AN record.'
 ERROR: ___ in AN record field (3,4,6) is not valid.
 ERROR: ID of ___ on AN record is not on any CP record.
 ERROR: Year in AN field 9 of ___ is less than JC field 2 YRST of ___
 ERROR: Year ___ in AN record field 10 exceeds NYRS on JC record.
 ERROR: CP identifier of ___ from EP record matches no identifier on the CP records.
 ERROR: Read CD of ___ which is not valid for HIN file.

Written to HMS File from Subroutine EPADD

ERROR: ID of ___ from EP record matches no identifier on the CP records.
 ERROR: Read CD of ___ when expecting an EP record.

Written to HMS File from Subroutine FLOWADJ

ERROR: JC(3) of ___ on JC record is not valid.
 ERROR: AS(3,4,5) of ___ on AS record is not valid.
 ERROR: ID of ___ on AS record matches no identifier on the CP records.
 ERROR: CD of ___ found when expecting (FA,SC) record.
 ERROR: In reading (FA,SC) record for CP ____, read year of ___ when expecting ___
 ERROR: RS(1,2,3,4,5,6) of ___ on RS record is not valid.
 ERROR: The identifier ___ on RS record matches no reservoir identifier on SV records.
 ERROR: Interpolation of SV/SA records is out of range for reservoir ___
 ERROR: In performing flow adjustments, reached end of input file (unit=___) without reading ED record.

Locating Errors in Data Storage System (DSS) Files

The WRAP programs read input files and create output files in both text format and binary DSS format. Most of the previously discussed input data errors can occur regardless of whether the data is read from text files or a DSS file. This last section of Chapter 9 focuses on additional problems related specifically to DSS files.

The Hydrologic Engineering Center (HEC) Data Storage System (DSS) is introduced in the preceding Chapters 1 and 6 of this *Reference Manual*. WRAP applications of DSS and its *HEC-DSSVue* interface are outlined in more detail in Chapter 6 of the *WRAP Users Manual* [2]. DSS and *HEC-DSSVue* are documented in great detail in the *HEC-DSSVue User's Manual* [9]. Routines from a HEC-DSS library are incorporated at compilation into the Fortran code of *SIM*, *SIMD*, *TABLES*, *HYD*, *SALT*, and *DAY* allowing creation of and access to DSS files. The WRAP programs contain options to create DSS files and both read and write data to DSS files.

HEC-DSS Trace and Error Messages

The HEC-DSS library routines distributed by the Hydrologic Engineering Center and incorporated into the WRAP programs include trace and error messages that are written to the message file. The message files in *SIM/SIMD*, *TABLES*, *HYD*, and *DAY* have filename extensions MSS, TMS, HMS, and DMS, respectively. The DSS messages are written to the MSS, TMS, HMS, and DMS files along with the other messages generated by *SIM*, *TABLES*, *HYD* and *DAY*. However, the DSS messages are in the DSS format controlled by the HEC-DSS library routines.

SIM and *SIMD* input parameters creating and accessing DSS files are contained on the DSS file options *OF* record and job options *JO* record. *TABLES* parameters dealing with DSS files are entered on the FILE record, DSSM, DSSD, and 7DSS records, types 2 and 6 time series records, and 4ZZZ record described in the *Users Manual* and other records covered in the other manuals. *HYD* parameters controlling DSS files are entered on the *HYD* job control *JC* record.

The HEC-DSS routines create a variety of different types of messages. A DSS parameter sets the level of messages to be written to the message file. For *SIM*, this optional parameter is entered as DSS(6) in *OF* record field 7. The parameter controlling the DSS message level is entered in the *TABLES* FILE record field 2 and *HYD* *JC* record field 19. Each of the DSS message levels defined in Table 9.11 includes all of the messages from preceding lower levels plus additional messages.

Table 9.11
DSS Message Levels

Level	Type of Message
-1	Only messages indicating program has aborted due to some problem.
1	Statements indicating that a DSS file has been opened or closed.
2 (default)	Error and warning messages if DSS problems are encountered.
3	Trace of all DSS records written to DSS files.
4	Trace of all DSS records read from DSS files.
5 and 6	Not used.
7, 8, and 9	Beginning, intermediate, and maximum level of debugging messages.

Level 2 is activated by default unless another option is selected. Levels 3 and 4 include listing of records by pathname as they are read from or written to a DSS file as well as the messages also activated at the lower levels. Levels 7, 8, and 9 provide debugging messages for the DSS subroutines of interest to programmers which hopefully WRAP users will never see nor need.

The IOSTAT status parameter values recorded in the message file provide information that may assist in understanding errors. IOSTAT codes are listed below. The program is terminated if IOSTAT is not zero.

```
IOSTAT = 0   DSS file was successfully opened.
IOSTAT = -1  Unable to create the DSS file.
IOSTAT = -2  Unable to connect to the DSS file.
IOSTAT = -3  Incompatible DSS versions.
IOSTAT = -4  No filename was provided.
IOSTAT = 0   All data was successfully retrieved.
IOSTAT = 1, 2, 3 Some data were found but some data are missing.
IOSTAT = 4   No data was found within the specified time window.
IOSTAT = 5   No data records were found.
IOSTAT > 10  Fatal error occurred. Program terminated.
```

Missing File, Record, or Data

The DSS-related errors that are most likely to occur in applying the WRAP programs are a missing file, one or more missing records in a file, or missing data in a record. The error message below from a *SIM* message file was generated because an expected input file with filename FundExamHYD.dss was not found.

```
-----DSS---ZOPEN:  New File Opened,  File: FundExamHYD.dss
                    Unit:  25;  DSS Version: 6-WA
*** Starting to read flows from DSS file.
    Number of control points = 11
-----DSS*** ZRRTS:  CAUTION - Data block not found in file.  Unit:  25
Pathname:  /FUNDEXAM/PK/IN/01JAN1940/1MON//
ERROR: DSS IOSTAT error 5 occurred reading flows from DSS file: FundExam
```

Having found no file with the expected filename, program *SIM* created an empty DSS file and then unsuccessfully attempted to read a DSS record with the following pathname from the empty file. The error is corrected by making the correct DSS input file available to *SIM*.

```
/FUNDEXAM/PK/IN/01JAN1940/1MON//
```

SIM and the other WRAP programs create DSS output files as needed. If the required output file does not exist, *SIM* or the other WRAP program creates a DSS file and stores output data in the file. If the output file already exists, the program writes output to the existing DSS file. Existing DSS records with the same pathname are over-written (replaced). With no existing DSS records with the pathname of the current output record found in the existing DSS file, the output record is added to the DSS file. This is different than the WRAP text-format output files which are entirely replaced with each execution of the WRAP program.

The following error message in the *SIM* message MSS file is triggered by missing naturalized flow data for two months on a *IN* record for control point Belton.

```
*** Starting to read flows from DSS file.
    Number of control points = 11
ERROR: DSS IOSTAT error 1 occurred reading flows from DSS file: FundExam
```

The error message provides an indication that input data is missing but no information regarding which data is missing. Therefore, the input parameter DSS(6) in *OF* record field 7 is changed to message level 4 (Table 9.11) and *SIM* is executed again. The trace information replicated below is written to the MSS file with message level 4 activated.

```

*** Starting to read flows from DSS file.
    Number of control points = 11
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/PK/IN/01JAN1940/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/PK/IN/01JAN1950/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/PK/IN/01JAN1960/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/PK/IN/01JAN1970/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/PK/IN/01JAN1980/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/PK/IN/01JAN1990/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/PK/IN/01JAN2000/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/PK/IN/01JAN2010/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/WHIT/IN/01JAN1940/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/WHIT/IN/01JAN1950/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/WHIT/IN/01JAN1960/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/WHIT/IN/01JAN1970/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/WHIT/IN/01JAN1980/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/WHIT/IN/01JAN1990/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/WHIT/IN/01JAN2000/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/WHIT/IN/01JAN2010/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/WACOL/IN/01JAN1940/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/WACOL/IN/01JAN1950/1MON//
----DSS--- ZREAD Unit 25; Vers. 2: /FUNDEXAM/WACOL/IN/01JAN1960/1MON//

```

Twenty-two lines of the repetitive message are omitted here to save space.

```

----DSS--- ZREAD Unit 25; Vers. 3: /FUNDEXAM/BELTON/IN/01JAN1940/1MON//
----DSS--- ZREAD Unit 25; Vers. 3: /FUNDEXAM/BELTON/IN/01JAN1950/1MON//
----DSS--- ZREAD Unit 25; Vers. 3: /FUNDEXAM/BELTON/IN/01JAN1960/1MON//
----DSS--- ZREAD Unit 25; Vers. 3: /FUNDEXAM/BELTON/IN/01JAN1970/1MON//
----DSS--- ZREAD Unit 25; Vers. 3: /FUNDEXAM/BELTON/IN/01JAN1980/1MON//
----DSS--- ZREAD Unit 25; Vers. 3: /FUNDEXAM/BELTON/IN/01JAN1990/1MON//
----DSS--- ZREAD Unit 25; Vers. 3: /FUNDEXAM/BELTON/IN/01JAN2000/1MON//
----DSS--- ZREAD Unit 25; Vers. 3: /FUNDEXAM/BELTON/IN/01JAN2010/1MON//
ERROR: DSS IOSTAT error 1 occurred reading flows from DSS file: FundExam

```

The last DSS record read has the pathname /FUNDEXAM/BELTON/IN/01JAN2010/1MON// which is an indication that this *IN* record probably has missing data. Correcting the error requires that the months of missing naturalized flows be found and corrected. *HEC-DSSVue* provides features for quickly finding periods of missing data in one or many DSS records. The one or more suspect records are tabulated using the *HEC-DSSVue* menu path *Display/Tabulate/Edit/Allow Editing*. The *View* feature of the editor has a *Show Missing As -M-* (or other user selected term) option. The *Find* option finds all periods of missing data (blanks replaced with -M-) in the one or more tabulated records. The user can type in quantities in the blank periods to replace the -M-.

HEC-DSSVue and DSS function with either regular or irregular interval data series. The WRAP programs use only regular interval data, meaning the data records must include quantities for all days, months, or years of the period-of-analysis. The *HEC-SSP* flood frequency example in Chapter 9 of the *Daily Manual* provides an example of other non-WRAP software (in this case *HEC-SSP*) that require the irregular data option meaning a constant interval is not necessary. Regular data is converted to the irregular option using the following *HEC-DSSVue* menu path:

Tools/Time Functions/Regular to Irregular (or vice versa *Irregular to Regular*).

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APPENDIX B GLOSSARY

Each of the terms included in this glossary is defined and discussed in more detail in the chapters of the manual. Terms are defined specifically from the perspective of their use in this manual.

active pool – Reservoir storage zone from which releases and withdrawals are made from the active pool. The inactive pool defined on the *WS* record can be drawn-down only by evaporation.

adjusted net evaporation-precipitation – *JD* record field 10 and *CP* record field 9 activates a *SIM* option to account for the portion of the reservoir water surface evaporation-precipitation that is also reflected in the naturalized streamflow inflows. The ratio of reservoir surface area to watershed area is used to determine the proportion of the naturalized streamflow that is runoff from the land now covered by the reservoir. The net evaporation-precipitation rate is adjusted to prevent double-counting this inflow.

artificial control point, water right, and reservoir – Parameter ARTIF on the *CO* and *WO* record allows control points, water rights, and reservoirs to be designated as artificial. Simulation result quantities associated with artificial system components are excluded from the *SIM* or *SIMD* output files unless certain output options are selected on the *JD* and *RO* records. The artificial designation does not affect the simulation computations. The artificial designation is designed for dealing with water accounting schemes involving "dummy" or artificial storage and diversions for accounting purposes that do not represent actual real storage and diversions. The artificial designation is designed to clarify simulation input and output.

available streamflow – The streamflow available to a water right is computed by *SIM* as an initial step as each right is considered in the water rights priority loop which is embedded within the monthly loop.

backup right – A backup water right activated by a *BU* record adds any shortage incurred by the other right being backed-up to its own target. Thus, multiple rights may be assigned to meet a particular target. The secondary backup right supplies the target only to the extent that the other right can not due to insufficient water availability.

binary file – The programs *SIM* and *SIMD* record simulation results in an output file with extension OUT which can optionally be in either text or binary format. Files in either format can be read by *TABLES*. The default is for the OUT file to be created as a text file that can be read using text editors such as MS WordPad. The parameter OUTFILE on the *JD* record allows the output OUT file to be created as an unformatted binary file. The binary file has the disadvantage of not being accessible to most editors and the advantages of maintaining the full level of precision of the computed data and reducing computer execution time.

channel loss credits – Credits represent increases in streamflow to result from incorporating channel losses in the *SIM/SIMD* simulation. Streamflow depletions from diversions and refilling storage reduce stream flows at downstream control points less if channel losses are considered.

channel loss factor – The channel loss factor CL entered on the *CP* record is used to determine channel losses in the river reach below a control point as follows where Q_{upstream} is the flow at the control point: $\text{channel loss} = CL Q_{\text{upstream}}$

- channel losses** – Channel losses represent the portion of the streamflow in the reach between two control points that is lost through infiltration, evapotranspiration, and diversions not reflected in the water rights. Channel loss L is treated as a linear function of the flow $Q_{upstream}$ at the control point defining the upstream end of the reach [$L = CL Q_{upstream}$] where CL is a channel loss coefficient provided as *HYD* or *SIM* input.
- conditional reliability modeling** – An optional modeling approach activated by *SIM CR* record and *TABLES* type 5 records analyzes water supply reliabilities and flow and storage frequencies over relatively short periods of a month to several years conditioned upon specified preceding reservoir storage conditions as described in Chapter 8 of this *Reference Manual*.
- constant inflow or outflow** – An option allows a set of 12 flows for the 12 months of the year entered on *CI* records to be either added or subtracted from streamflow each year. These flows may represent intrabasin or interbasin water transport, return flows from groundwater sources, losses or other flows not otherwise reflected in the water rights input.
- control point** – Control points are stations or nodes which provide a modeling mechanism for representing the spatial connectivity of system components. The locations of system features are defined by control points. The spatial configuration of the system is delineated by specifying the control point located immediately downstream of each control point.
- curve number method adaptation** – This method of distributing flows described in Chapter 3 is based on a modified version of the Natural Resource Conservation Service (NRCS) rainfall-runoff modeling methodology which uses the curve number CN to represent the land cover and soil types of the watersheds.
- daily modeling system** – The WRAP simulation model *SIMD* (D for daily) and associated features of *TABLES* allow a sub-monthly computational time step such as daily as described in the *Daily Manual*. The WRAP programs *DAY* and *DAYH* facilitate developing *SIMD* input.
- Daily Manual** – TWRI Technical Report 340 entitled *Water Rights Analysis Package (WRAP) Daily Modeling System* documents the WRAP programs *SIMD* and *DAY*.
- DAY and DAYH** – The daily WRAP modeling system described in the *Daily Manual* includes the computer programs *DAY* and *DAYH* used for developing certain *SIMD* input data.
- delivery factor** – In considering channel losses, the delivery factor is one minus the channel loss factor ($DF = 1 - CL$) and represents the fraction of the flow at the upstream control point that reaches the next downstream control point.
- disaggregation** – the daily simulation model *SIMD* includes features for disaggregating (distributing) monthly naturalized flow and water use targets over the days of each month.
- diversion** – Computed by *SIM* as a diversion target limited by water availability. The water supply diversion requirement minus the computed diversion is the computed shortage.
- drainage area ratio method** – Naturalized flows at an ungaged site are estimated from flows at a gaged location based on proportioning the flows in proportion to the drainage areas of the gaged and ungaged watersheds. $Q_{ungaged} = R_{DA} Q_{gaged}$ where R_{DA} is the drainage area ratio
- drought index** – A drought or storage index (*DI/IP/IS* records) allows diversion, instream flow, and hydropower requirements to be specified as a function of the storage content of specified reservoirs. The drought index is expressed in the format of a table of storage content versus

a percentage multiplier which is applied to the target diversion, instream flow, or hydropower amount associated with a water right.

DSS – WRAP programs create, read, and write to DSS files in the direct access binary format of the Data Storage System (DSS) developed by the USACE Hydrologic Engineering Center. DSS files with SIM, SIMD, and SALT are read with HEC-DSSVue for plotting, data transformation operations, and statistical analyses.

dual simulation option – An automated dual simulation activated by the *JO*, *SO* or *PX* record allows streamflow depletions during a first simulation with specified water rights to serve as a limit on streamflow depletions during a second simulation with modified water rights.

equal weight option – Two alternative strategies can be adopted for assigning probabilities to each of the multiple hydrologic simulation sequences in conditional reliability modeling. The equal-weight option is based on weighting each hydrologic sequence equally. The alternative probability array option assigns probabilities to each hydrologic sequence.

energy requirement – An annual hydroelectric energy target in units of megawatt hours per year or similar units is entered in *WR* record field 3. *SIM* determines a monthly energy target by combining the annual target with monthly distribution factors (*UC* records) and other optional target setting records. An energy target is determined the same as a diversion target.

environmental flow standards – The *SIM* and *SIMD* environmental standard *ES*, hydrologic condition *HC*, and pulse flow *PF* records for modeling *IF* record instream flow rights are motivated by Senate Bill 3 environmental flow standards.

evaporation – Evaporation from the water surface of reservoirs is included in the volume accounting computations by combining depths from *EV* records with water surface areas determined as a function of storage volume. The evaporation in WRAP is actually a net evaporation minus precipitation depth or volume.

evaporation-precipitation – Net evaporation minus precipitation depth or volume. Evaporation represents a loss of water from the reservoir. Conversely, precipitation is a gain.

evaporation-precipitation rate – Monthly rates expressed as depths of evaporation minus precipitation are provided as model input in inches, feet, or other units of depth per month.

evaporation-precipitation volume – In the water volume accounting computations, the monthly net evaporation-precipitation volume is determined as the rate (depth/month) multiplied by the average surface area of the reservoir for the month.

exceedance frequency – The percentage of the total months in the overall simulation period-of-analysis that a particular amount is equaled or exceeded. *TABLES* develops exceedance frequency relationships for naturalized, regulated, and unappropriated streamflow, instream flow shortage, reservoir storage, and reservoir water surface elevation.

filename extension – The filename of the input and output files for the WRAP programs consist of a filename root assigned by the model user appended with standard three-character extensions indicating the type of data that is contained in the file.

firm yield – The maximum water supply diversion or hydropower electric energy generation that can be achieved with a volume and period reliability of one-hundred percent (to a defined level of

precision) based on the premises reflected in the model. The *SIM* firm yield *FY* record activates an automated iterative search for the firm yield.

flood control operations – Operation of reservoirs for flood control is simulated by flood control *FC* and flood flow *FF* records that are included only in the daily *SIMD*, not *SIM*.

flow distribution methods – Several alternative methods are described in Chapter 3 of this *Reference Manual* for synthesizing naturalized streamflows at ungaged (unknown flow) control points based on known flows at other control points read from *IN* records and watershed parameters from a flow distribution *DIS* file.

flow distribution equation – $Q_{\text{ungaged}} = a (Q_{\text{gaged}})^b + c$ with coefficients *a*, *b*, and *c* input on *FC* records is one of several flow distribution methods. With default values of one and zero for *b* and *c* and the drainage area ratio used for the coefficient *a*, the equation reduces to the drainage area ratio method.

flow switch – The flow switch *FS* record inserts a switch in the process of setting an instream flow target or other target each month of the *SIM* simulation based on either the cumulative volume of a specified variable or count of occurrences of meeting a specified criterion.

Fundamentals Manual – TWRI Technical Report 283 entitled *Fundamentals of Water Availability Modeling with WRAP* provides an introductory overview of the basic features of the WRAP programs *WinWRAP*, *SIM*, and *TABLES*.

head – The vertical water surface elevation difference between upstream and downstream of the turbines used in the power equation (Equation 4.4 of Chapter 4). *SIM* computes head as a reservoir water surface elevation minus tailwater elevation.

HEC-DSS – The Hydrologic Engineering Center (HEC) Data Storage System (DSS) developed by the HEC of the U.S. Army Corps of Engineers is a database management system used with both HEC and non-HEC simulation models including WRAP.

HEC-DSSVue – The USACE Hydrologic Engineering Center HEC-DSS Visual Utility Engine is a user-friendly software package for managing, plotting, and manipulating data in DSS files. WRAP programs write simulation results to DSS files for transport to HEC-DSSVue.

HYD – Pre-simulation utility program is used to develop hydrology input for *WRAP-SIM*.

hydroelectric energy – Simulation of hydroelectric energy generation in *SIM* is explained in Chapter 4 of this manual.

hydrologic condition – Specified on *HC* records for use with *ES* and *PF* records in modeling EFS.

Hydrology Manual – TWRI Technical Report 341 entitled *Water Rights Analysis Package (WRAP) River System Hydrology* documents the WRAP program *HYD* which facilitates developing and updating hydrology input data for the *SIM* simulation model.

hydrologic simulation period – In a *WRAP* simulation, specified annual water use requirements, distributed over the 12 months of the year, are met, subject to water availability, during a hypothetical repetition of historical hydrology represented by sequences of naturalized streamflows and net evaporation-precipitation rates for each month of a multiple-year hydrologic simulation period, which is also called the hydrologic period-of-analysis.

hydrologic period-of-analysis extension – Methodologies for updating (extending forward) the hydrologic period-of-analysis are described in the *Hydrology Manual*.

inactive pool – The bottom pool of a reservoir from which releases or withdrawals cannot be made except by evaporation. The inactive pool storage capacity is entered in *WS* record field 7.

incremental streamflows – An incremental flow is the difference between total flows at adjacent control points. *WRAP* computational algorithms, as well as input and output data, are based on total flows rather than incremental inflows. However, *HYD* and *SIM* include options for checking for negative incremental naturalized streamflows and adjusting the flows to remove the negative incrementals. Incremental flow options are controlled by *JD* record fields 8 and 9.

inflows to a control point – This quantity referenced in *TO* record fields 5 and 6 and *FS* record field 2 and tabulated by the *2CPI* record represents inflows into a control point excluding releases from secondary reservoirs located upstream for water rights located downstream of the control point. The inflow is computed as the regulated flow plus streamflow depletion at the control point minus secondary reservoir releases.

instream flow requirement – A water right requirement entered on an *IF* record consists of placing a minimum target limit on the regulated flows at a control point. The objective is to maintain regulated streamflows at or greater than the target if feasible.

junior right – see senior or junior rights

lakeside versus downstream water supply release – *WS* record field 11 allows specification of whether or not water supply diversions are used to generate energy for more junior hydropower rights. By default, diversions for senior water rights are allowed to pass through the turbines to generate power for junior hydropower rights. However, the lakeside diversion option activated by *WS* record field 11 for a diversion right results in the diversion bypassing the turbines and not contributing to power generation.

multiple-reservoir system operations – A single water right diversion, instream flow, or hydroelectric power target may be met by releases from multiple reservoirs following rules specified on *OR* records. Multiple-reservoir release rules are based upon balancing the storage content expressed as a percentage of capacity in specified vertical active pool zones of each system reservoir.

natural priority option – Water right priorities are ordered internally within *SIM* in upstream to downstream order if the natural priority option is specified in the *JO* record. This ranked order is used in lieu of the water right priorities entered on *WR* records.

naturalized streamflows – Sequences of monthly streamflows representing natural hydrology are developed typically by adjusting historical gaged streamflow data to remove the impacts of reservoir construction, water use, and other human activities. Naturalized streamflows are provided as *SIM* input data on inflow *IN* records. The naturalized flows in the *SIM* output OUT file read by *TABLES* with a *2NAT* record include flow adjustments from FAD file *FA* records if FAD option 1 is employed.

pathname – records in DSS files are identified by pathnames consisting of six component parts.

pattern hydrographs – the daily simulation model *SIMD* disaggregates monthly naturalized stream flows over the days of the month in proportion to daily flows input on *DF* records (call daily pattern hydrographs) while maintaining the monthly volumes.

period reliability – The reliability index reflected in Equation 7.2 is the percentage of the total months or years (periods) in the overall simulation period-of-analysis that a specified percentage of a diversion target or hydroelectric energy target is supplied.

permitted, authorized, or target diversion – The diversion requirement or target amount of water to be appropriated from streamflow at a control point location and reservoir storage at the same or other locations.

permitted, authorized, or target energy requirement – Hydroelectric energy generation target.

precipitation – Precipitation falling directly on the water surface of reservoirs is included in the reservoir volume accounting computations through the net evaporation-precipitation depth.

primary and secondary control points – Naturalized streamflows are input to *SIM* on *IN* records for primary (known-flow or gaged) control points. Secondary control points are locations for which naturalized streamflows are computed in *SIM* from flows at one or more primary control points and watershed parameters used methods outlined in Chapter 3.

primary and secondary reservoirs – The terms primary reservoir and secondary reservoir are defined in the context of water rights. Primary reservoirs are refilled by the water right in question; secondary reservoirs are not refilled. Any number of reservoirs can be associated with each water right. However, storage capacity can be refilled in only one primary reservoir. The other secondary reservoirs make releases to meet diversion, instream flow, or hydropower requirements but cannot be refilled by the water right. A secondary reservoir for one water right can be a primary reservoir for another water right and vice versa.

priority – An integer value associated with a water right indicating the seniority of the right relative to all the other rights. In each period of the simulation, water rights are considered in turn and available water appropriated in order of their relative priorities. Priorities are entered on the *WR* and *IF* records and may be adjusted by options on the *UP* records or replaced by the natural priority option activated with the *JO* record.

priority circumvention options – The *PX* record controls four different modeling features designed to deal with water management situations in which the normal priority system is not applicable. Water management actions evade the priority sequence in the model.

probability array option – Two alternative strategies can be adopted for assigning probabilities to each of the multiple hydrologic simulation sequences in conditional reliability modeling. The equal-weight option is based on weighting each hydrologic sequence equally. The alternative probability array option computes probabilities for each hydrologic sequence.

Programming Manual – TWRI Technical Report 388 entitled *Water Rights Analysis Package (WRAP) Programming Manual* provides information regarding the Fortran code of each of the WRAP programs. The *Programming Manual* facilitates maintenance and improvements to the Fortran programs but is not needed to apply the modeling system.

pulse flows – Environmental instream flow requirements for high flow pulses are modeled by pulse flow *PF* and pulse flow options *PO* records that are included only in the daily *SIMD*.

Reference Manual – WRAP is documented by this *Reference Manual* and companion *Users Manual*, *Fundamentals Manual*, *Daily Manual*, *Hydrology Manual*, and *Salinity Manual*.

regulated streamflows – *SIM* computed regulated flows, associated with a particular control point, represent the physical streamflow after accounting for all the water rights. The *SIM* simulation

starts with naturalized flows and computes regulated flows. Regulated flows may be greater than unappropriated flows because a portion of the regulated flows may be committed to meet instream flow requirements or downstream diversion or storage rights.

record – Data is recorded in input and output files as records. A record is one line of data in a text file or a time series referenced by a pathname in a DSS file. Input records are described in the *Users Manual*. Output records are described in Chapter 5 of this *Reference Manual*.

return flow – An amount of water computed as the diversion multiplied by an inputted return flow factor is returned to the stream system at a user-specified control point in either the same month as the diversion or the next month as specified by the *WR* record. Return flows may also be modeled as constant inflows entered on *CI* records.

routing – *SIMD* has two alternative routing algorithms described in the *Daily Manual* that model the downstream propagation of streamflow depletions and return flows, a recommended standard lag and attenuation method and an adaptation of the Muskingum routing method.

run-of-river water right – A water right with zero reservoir storage capacity.

safe yield – A *SIM* feature for automating the iterative routine for computing firm yield or safe yield is controlled by the *FY* record. Both firm and safe yield are metrics for assessing water supply or hydropower capabilities. Safe yield is an expanded version of firm yield that adds options for specifying a water supply reserve or allowable shortages.

Salinity Manual – TWRI Technical Report 317 entitled *Salinity Simulation with WRAP* documents the WRAP program *SALT* and salinity related features of *TABLES*.

SALT – The original *WRAPSALT* completed in 1994 expands *WRAP3* to incorporate features for considering salinity in assessing water supply reliability. A completely redesigned *SALT* developed during 2004-2008 reads a *SIM* output file and salinity input file and tracks salt loads and concentrations through the river/reservoir system.

seasonal rule curve operations – A model option activated by the *MS* record allows the storage capacity of a reservoir to vary monthly over the 12 months of the year. The primary application of this option is modeling reservoirs with operating plans based on seasonal allocations of storage capacity between flood control and conservation pools.

secondary control points – See primary and secondary control points.

secondary energy – Additional hydroelectric energy, above the permitted energy target, which could be generated incidentally by pass-through flows and releases for more senior water right diversions.

secondary reservoirs – See primary and secondary reservoirs.

senior or junior rights – A water right is senior or junior relative to another water right depending on the priority number included in the input data for each right. A senior right has the highest priority, which is represented by the smallest priority number (earliest date or other priority indicator) and is considered first in the water allocation computations.

shortage – Diversion target minus actual diversion or energy target minus actual energy produced. A shortage is the amount of a diversion or energy target not supplied due to insufficient streamflow and/or reservoir storage being available to meet the full target.

SIM – This main program simulates a river/reservoir/use water allocation system.

- SIMD** – This expanded version of *SIM* has sub-monthly time step, flow forecasting, flow routing, and flood control operations added.
- spring flows** – Spring flows from groundwater have been treated as a separate component of naturalized flows in some TCEQ WAM System datasets by use of flow adjustment *FA* records in a *SIM* input file with filename extension FAD.
- storage-area relationship** – A relationship between reservoir storage volume and water surface area is required in the computation of net evaporation-precipitation volumes. This relationship may be input alternatively as a storage versus area table (*SV/SA* records) or as coefficients for an equation (*WS* record fields 4, 5, 6).
- storage-elevation relationship** – A relationship between reservoir storage volume and water surface elevation is required in the computation of head in the hydropower routine. This relationship is input as a storage volume versus elevation table (*PV/PE* records).
- streamflow depletion limit** – Limits may be placed on the amount of streamflow a right can appropriate in a year, season, or month of the year to meet streamflow and storage targets using options on the *SO* record.
- streamflow depletion** – *SIM* computed streamflow depletions are the amounts appropriated to meet water right diversions, account for reservoir net evaporation-precipitation, and/or refill reservoir storage. Each streamflow depletion is associated with a particular right.
- TABLES** – This post-simulation program develops tables, data listings, and reliability indices from *SIM* input and output files that organize/summarize the simulation results.
- tailwater** – The water surface elevation downstream of a hydropower plant is used in computing head. The tailwater elevation may be entered as a constant on a *HP* record, or alternatively a table of tailwater elevation versus discharge (*TE/TQ* records) may be entered.
- TAMUWRAP** – The original 1988 version of the WRAP model was called the *Texas A&M University Water Rights Analysis Program (TAMUWRAP)*.
- target** – Diversion, instream flow, or hydroelectric power generation demand/need/requirement associated with a water right. *WR*, *UC*, *DI*, *SO*, *TO*, *TS*, and *FS* records provide options for use in setting targets. The water right type 7 feature (*WR* record field 6) allows reservoir storage targets to be set in the same manner as diversion targets but limited to not exceed the conservation storage capacity. Targets are met to the extent allowed by water availability.
- target series** – Diversion, instream flow, and hydropower requirements are typically modeled as varying seasonally but being constant from year to year. However, the target series *TS* record allows specifying targets that vary between years as well as between months.
- time interval** – The version of *WRAP* documented by this manual uses a computational time step of one month. Expanded features documented by the *Daily Manual* allow use of a daily or other sub-monthly time interval.
- transient priority water right** – options activated by the *PX* record assign two priorities to a water right. Transient priority option 1 allows a return flow to be assigned a priority different than the diversion. Transient priority option 2 allows a right to be activated and deactivated at different points in the priority sequence.

turbine capacity – An optional discharge capacity on the *HP* record in volume/month serves as an upper limit on the amount of water that can be released through turbines to generate energy. If not otherwise specified the turbine discharge capacity is assumed to be unlimited.

turbine inlet elevation – The optional inlet elevation entered on a *HP* record sets a minimum pool level below which power generation is curtailed. Power generation with all releases for all rights is constrained by the turbine inlet invert. Releases for a particular right are also constrained by the specified inactive pool. For a hydropower right with the inactive pool set higher than the turbine inlet, power generation with pass-through flows and water supply releases for other rights are constrained only by the turbine inlet elevation. Additional releases for the hydropower right are also constrained by the inactive pool.

type – The water right type defined in *WR* record field 6 specifies certain water management tasks and rules associated with the water right.

type 1 water right – allows a water supply diversion target and/or storage target in one reservoir to be met from streamflow depletions and releases from one or multiple reservoirs.

type 2 water right – is the same as a type 1 right except a reservoir storage target (refilling of storage capacity in the one reservoir) is not allowed.

type 3 water right – is the same as a type 2 right except the permitted diversion target can be met only from reservoir releases from storage, not streamflow.

type 4 water right – the target amount of water is discharged into the stream.

type 5 water right – is the same as a type 1 right except a hydroelectric energy generation target is specified rather than a diversion. Hydropower rights are either type 5 and or type 6.

type 6 water right – is the same as a type 3 right except a hydroelectric energy generation target is specified rather than a diversion. Same as type 5 except not allowed streamflow depletions.

type 7 water right – sets a reservoir storage target.

type 8 water right – sets a target for use by other rights but performs no other computations.

unappropriated streamflows –*SIM* computed unappropriated flows, associated with a particular control point, are the portions of the naturalized streamflows still remaining after the streamflow depletions are made and return flows are returned for all the water rights included in the simulation. The *SIM* simulation starts with naturalized flows and computes regulated and unappropriated flows. Unappropriated flows may be less than regulated flows because a portion of the regulated flows may be committed to meet instream flow requirements or downstream diversion or storage rights.

Users Manual – TWRI Technical Report 256 entitled *Water Rights Analysis Package (WRAP) Modeling System Users Manual* provides instructions for working with input files and records.

volume reliability – The total volume of actual diversions or total hydroelectric energy generated during the simulation period-of-analysis expressed as a percentage of the corresponding total permitted diversion or hydroelectric energy targets. Computed based on Equation 7.1.

water right – A *WRAP* water right is a set of water management capabilities and water use requirements associated with either a water right *WR* record or instream flow *IF* record and supplemental records associated with the *WR* or *IF* record. A water right may include

specifications for water supply diversion, return flow, hydroelectric energy generation, instream flow, and/or reservoir storage.

water use distribution coefficients – Each annual diversion, instream flow, and hydropower target is distributed over the 12 months of the year by a set of 12 multiplier factors on *UC* records.

water surface elevation – Reservoir water surface elevations determined based on linear interpolation of *PV/PE* record table are included in the OUT file on reservoir/hydropower records for all reservoirs for which *PV/PE* records are entered regardless of whether hydropower rights are associated with the reservoir. Reservoir water surface elevations are tabulated by the *TABLES 2WSE* record.

watershed flow option – This *SIM* option restricts the amount of water available to a water right to naturalized streamflow at its location computed by multiplying the naturalized flows input for the control point assigned to the water right by a factor which typically will be a drainage area ratio. Multiple water rights assigned to the same control point can have different limits on the amount of naturalized streamflow available to them.

WinWRAP – The user interface facilitates executing the WRAP programs within Microsoft Windows in combination with other Microsoft programs.

WRAP – The term *Water Rights Analysis Package (WRAP)* refers to the set of computer programs, *WinWRAP*, *TABLES*, *SIM*, *SIMD*, *HYD*, *DAY*, and *SALT* and associated documentation.

WRAP2 and **WRAP3** – The 1992 *Water Rights Analysis Program-Version 2 (WRAP2)* in combination with *TABLES* replaced the original *TAMUWRAP* and was superseded by *WRAP3* which provided essentially all the capabilities of *WRAP2* plus multiple-reservoir system operation, hydroelectric power, and other optional features not available in *WRAP2*. *WRAP3* is superseded by *WRAP-SIM*.

WRAP Display Tool – The WRAP Display Tool available from the TCEQ WAM website was developed at the Center for Research in Water Resources at the University of Texas at Austin for the TCEQ. The software tool facilitates spatial display of *SIM* simulation results in an ESRI ArcMap GIS environment.

WRAPNET – *WRAPNET* completed in 1993 provides the same modeling capabilities as *WRAP2*, but the internal computations are performed using network flow programming, a computationally efficient form of linear programming.

WRAPVIEW – The TNRCC and USGS developed *WRAPVIEW* in 1996 by combining *WRAP* with the *ArcView* Geographical Information System (GIS) software package. *WRAPVIEW* was never fully operational and is now obsolete.

zones 1 and 2 – For purposes of specifying multiple-reservoir operating rules, reservoir active pools may be divided into an upper and lower zones illustrated in Figures 4.1 and 4.2 by use of *OR* records. Release decisions are based on balancing the storage contents of comparable zones in multiple reservoirs in terms of contents as a percentage of zone capacity.

APPENDIX C EXAMPLES ILLUSTRATING SIM AND TABLES

The examples in Appendix C are designed to demonstrate WRAP modeling capabilities covered in Chapters 2, 3, and 4 of this *Reference Manual*. Other examples are found in Chapters 6, 7, and 8 of this *Reference Manual* and in the *Fundamentals*, *Daily*, *Hydrology*, and *Salinity Manuals*. The *Users Manual* is required to understand the input records of these examples as well as required to understand any *SIM* and *TABLES* input datasets. Input files for essentially all of the examples in all of the WRAP manuals, including those presented in this appendix and elsewhere in this manual, are distributed with the computer programs and manuals.

Ten examples are provided in this appendix to illustrate the basic features of the WRAP programs *SIM* and *TABLES*. These examples illustrate the format and content of input datasets explained in the *Users Manual* and simulation results explained in this *Reference Manual*. Water management features covered in Chapter 4 are a major focus, and hydrology features covered in Chapter 3 are also illustrated. Hypothetical river systems are modeled. Simple rather than realistic numbers are used in these ten examples to facilitate tracking of the model computations. Simple expressions are also adopted for the alphanumeric identifiers of control points, reservoirs, and water rights. Any descriptive label may be used for these identifiers. Only a few of the many possible tables of simulation results are developed with *TABLES*. An effective way for users to familiarize themselves with WRAP is to experiment by adding various features of interest to the examples, following the instructions in the *Users Manual*, rerunning *SIM* and *TABLES*, and analyzing the results to confirm that the model behaves as expected.

Expanded Versions of the Fundamentals Manual Example

Another much larger and more realistic example is presented in the *Fundamentals Manual* and expanded in the other manuals to explore particular model features. The example presented in detail in the *Fundamentals Manual* uses realistic input data to illustrate the basic capabilities of the WRAP programs *SIM* and *TABLES*. The *Fundamentals Manual* includes a *FY* record firm yield analysis that is expanded in Chapter 6 of this *Reference Manual* to include *FY* record safe yield criteria. Chapter 6 also includes an example with a *SIM ZZ* record and *TABLES 4ZZZ* and *4ZZF* records added to the *Fundamentals Manual* example to illustrate features for analyzing stream flow availability in the water rights priority sequence. Chapter 7 uses the *Fundamentals Manual* example to demonstrate the various program *TABLES* capabilities. The presentation of conditional reliability modeling (CRM) in Chapter 8 relies upon four CRM versions the *Fundamentals Manual* example. Daily versions of the *Fundamentals Manual* example are incorporated in the *Daily Manual* to illustrate explanations of *SIMD* and *TABLES* daily modeling capabilities. Likewise, salinity datasets are added to the *Fundamentals Manual* example to create the examples presented in the *Salinity Manual*.

SIM and TABLES Examples in Chapters 2 and 3 and Appendix C

The two examples in Chapter 2, one example in Chapter 3, and ten examples in Appendix C illustrate the basic WRAP simulation concepts and methods covered in Chapters 2, 3, and 4. These examples are listed in the table on the next page with the types of input files and records included in each example. Examples 1, 2, 3 of Appendix C provide a general introductory

overview of *SIM* and *TABLES*. Examples 4, 5, 6, 7, 8, 9, and 10 focus on different modeling options. The ten examples in Appendix C feature the following *SIM* simulation capabilities.

- Example 1 on page 387 – *WR* and *IF* record water rights with *DI/IS/IP* record drought indices.
- Example 2 on page 394 – *WR, IF, SO, TO, ML* water right options and *MS* reservoir operations.
- Example 3 on page 399 – Hydropower *HP* and multiple-reservoir system operation *OR* records.
- Example 4 on page 410 – DIS file *FD* and *WP* record naturalized flow distribution options.
- Example 5 on page 416 – Target options *TO* record and target series *TS* record.
- Example 6 on page 420 – Multiple-owner reservoir modeled using *EA, EF, and AF* records.
- Example 7 on page 425 – Multiple-reservoir system operations modeled with *OR* records.
- Example 8 on page 432 – Water right with *FS* record flow switch.
- Example 9A on page 435 – Flow switch *FS* combined with *DI/IS/IP/IM* record drought index.
- Example 9B on page 440 – Flow switch *FS* combined with *DI/IS/IP/IM* record drought index.
- Example 10 on page 448 – Subordination agreement modeled by combining *PX* and *BU* records.

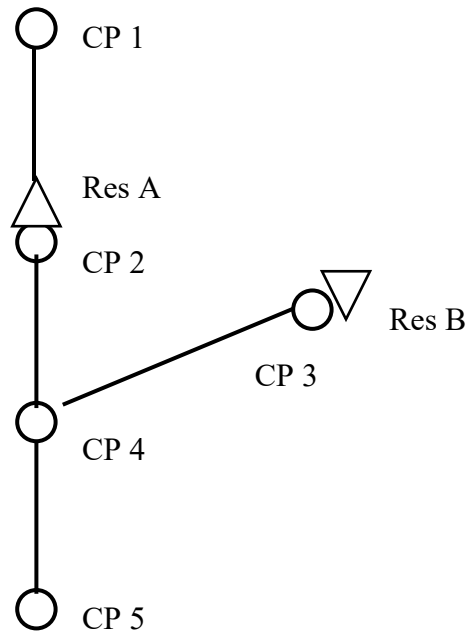
List of Input Files and Input Records Employed in the Examples

Example	<i>SIM</i> Input Files	<i>SIM</i> Input Records	<i>TABLES</i> Input Records
<u><i>SIM and TABLES Examples Presented in Chapters 2 and 3</i></u>			
1	DAT	T1,JD,CP,WR,ED,FO,EV,ED	
2	DAT	T1,JD,JO,UC,CP,IF,WR, WS,SV,SA,IN,EV,ED	2SCP,2REL,2FRE,2FRQ, 2STO,2REG,2UNA
3	DAT	T1,JD,CP,WR,ED,FO,EV,ED	
<u><i>SIM and TABLES Examples Presented in Appendix C</i></u>			
1	DAT, FLO, EVA, DIS	T1,T2,JD, UC,CP,IF,WR,WS, SV,SA,DI,IS,IP,IN,EV,FD,WP	PAGE,2REL, 2FRE,2FRQ,IDEN
2	DAT, FLO, EVA	JD, RO,UC,RF,CP,CI, IF, WR,WS,SO,TO,ML,MS,IN,EV	2SCP, 2REL, 2RES
3	DAT	T1,JD,RO,UC,CP,IF,WR,WS, HP,OR,SV,SA,PV,PE,IN,EV	2REL,2FRE,IDEN 2REG,2UNA
4	DAT, DIS	JD, WR, CP, FD, FC, WP	2NAT
5	DAT, FLO	T1,T2,JD,JO,CP,IF, WR,WS,TO,TS, IN	2NAT,2REG,2STO, 2DIV,2SHT,IDEN
6	DAT	JD,JO,CP,WR,SV,SA,EA, EF,AF,IN,EV	2SWR,2SCP
7	DAT	JD,JO,RO,CP,WR,WS,OR,IN	2DIV,2ROR,2RSD,2RES,4HRR
8	DAT	JD,JO,CP,WR,FS,IN	2TAR, 2DIV, 2REG, IDEN
9	DAT	JD,JO,CP,WR,IF,FS, DI,IS,IP,IM,IN	2FSV, 2FSC, 2REG, IDEN, 2TAR, 2TAR, 2IFT
10	DAT	JD,JO,PX,BU,WR,WS,CP	2TAR,IDEN,2XAV,2DEP

WRAP-SIM and TABLES Example 1

Example 1 illustrates the fundamentals of applying *SIM* and *TABLES*. A system represented by five control points, two reservoirs, seven *WR* record water rights, and an *IF* record instream flow water right. Drought indices are applied with three of the water rights.

Default input and output files are used in Example 1; thus, a *JO* record *INEV* entry is not required. Input data files are printed on the following pages. Filenames are exam1.DAT, exam1H.FLO, exam1H.EVA, and exam1H.DIS. *SIM* creates output files with filenames exam1.OUT and exam1.MSS. Neither is reproduced here. The message file (filename exam1.MSS) provides the trace messages shown in the *Users Manual* indicating the simulation progressed to a normal completion. *TABLES* reads the file exam1.OUT and organizes the simulation into selected tables. *TABLES* input and output files (filenames exam1.TIN and exam1.TOU) are reproduced here following the *SIM* input. The spatial configuration of the river basin system is shown in the following schematic.



System Schematic for Example 1

Hydrology for Example 1

A 3-year 2015-2017 hydrologic period-of-analysis is adopted. A 50 to 80 year period-of-analysis would be more representative of actual modeling applications, but we need to keep the examples small. Naturalized stream flows, in acre-feet/month, are provided as input on *IN* records for control points CP-2, CP-3, and CP-5. Naturalized stream flows at CP-1 are synthesized by transferring flows from CP-2 using the modified NRCS CN method. Flows at CP-4 are synthesized by applying the drainage area ratio method with channel losses to the incremental

flows at CP-5 from the subwatershed below CP-2 and CP-3. Channel loss factors of 0.10, 0.12, and 0.15, respectively, are entered on the *CP* records for CP-2, CP-3, and CP-4.

Net evaporation-precipitation depths in inches are provided on *EV* records for CP-2. These depths are converted to feet by the multiplier factor in field 5 of the *CP* record. Net evaporation-precipitation depths for CP-2 are repeated for CP-3 by *CP* record field 7. Since there are no reservoirs at CP-1, CP-4, and CP-5, *NONE* is entered in *CP* record field 7.

Water Rights for Example 1

Information for the seven *WR* record water rights is tabulated below.

Water Right	Water Right Owner	Location	Reservoir	Priority Number	Refilling Capacity (acre-feet)	Permitted Diversion (ac-ft/yr.)	Return Flow Factor	Instream Flow Target
WR-1	Mr. J. W. Smith	CP-1	-	1965	-	1,200	0.2	-
WR-2	Municipal District	CP-2	Res A	9999	80,000	-0-	-	-
WR-3	Irrigation District	CP-3	Res B	1975	30,000	42,000	0.1	-
WR-4	Irrigation District	CP-3	Res B	8888	40,000	40,000	0.35	-
WR-5	City of Jonesville	CP-4	Res A	1984	-0-	26,000	-	-
WR-6	Elm City	CP-5	Res A	1952	-0-	18,000	-	-
WR-7	State of Texas	CP-5	-	1111	-	-	-	12,000

Water right 1 is a run-of-river (no reservoir storage) irrigation diversion of 1,200 acre-feet/year at CP-1, distributed seasonally (*UC* records) as follows: 240 ac-ft in May and August and 360 ac-ft in June and July. Twenty percent of the water diverted each month is returned at CP-2. The priority number of 1965 represents the effective date of the water right permit.

Water right 3 includes a 42,000 ac-ft/year diversion from Reservoir B and filling storage to a capacity of 30,000 ac-ft with a priority number of 1975. Water right 4 consists of filling reservoir B to its full capacity of 40,000 ac-ft with a priority junior to all diversion rights but senior to filling storage in Reservoir A.

Water rights 5 and 6 are diversions for municipal use by the cities of Jonesville and Elm City from stream flows at CP-4 and CP-5, respectively, supplemented as necessary by releases from Reservoir A. Their water right permits have effective dates of 1984 and 1952 which set their priorities. Reservoir A is refilled by water right 2 with a priority junior to all other rights, represented by a priority number of 9999 which is larger than the priority numbers of all other rights but otherwise arbitrary. Any time the storage content of Reservoir A drops to 20,000 ac-ft (25% of capacity), a municipal demand management plan is implemented which reduces the diversion requirements to 80% of normal.

Water right 7 is an instream flow target at CP-5 that varies as a function of total system storage and is modeled using the drought index feature (*DI/IS/IS* records). The instream flow target varies linearly from 500 ac-ft/month (6,000 ac-ft/year) when both reservoirs are empty to

1,000 ac-ft/month (12,000 ac-ft/year) when the total storage is 60,000 ac-ft (50% of capacity). If the total storage content is between 60,000 and 108,000 ac-ft, the instream flow requirement is set at 1,000 ac-ft/month. If storage rises above 108,000 ac-ft, the flow target increases to 1,200 ac-ft/month. The drought index is as follows.

Total Storage Content of Reservoirs A and B (acre-feet)	Instream Flow (ac-ft/month)	Instream Flow as a Percentage of 1,000 ac-ft/month
0	500	50%
60,000	1,000	100%
60,000 to 108,000	1,000	100%
108,001 to 120,000	1,200	120%

WRAP-SIM DAT File for Example 1

```

T1 Example 1 - WRAP-SIM Input File Exam1.DAT
T2 Example 1 from Appendix C of Reference Manual
**
**      ! 1      ! 2      ! 3      ! 4      ! 5      ! 6      ! 7 !
**345678901234567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !
**
JD      3      2015      1      -1      -1
**
**      Water Use Coefficients
**
UC      mun      0.06      0.06      0.06      0.06      0.06      0.10
UC      0.12      0.12      0.11      0.10      0.09      0.06
UC      irr      0.00      0.00      0.00      0.00      0.20      0.30
UC      0.30      0.20      0.00      0.00      0.00      0.00
**
**      Control Points
**
CP      CP-1      CP-2      4      NONE
CP      CP-2      CP-4      0.083333      0      0.10
CP      CP-3      CP-4      0      CP-2      0.12
CP      CP-4      CP-5      6      NONE      0.15
CP      CP-5      OUT      0      NONE
**
**      Water Rights
**
WR      CP-1      1200      irr      1965      0.2      WR-1
**
WR      CP-2      9999      WR-2
WS      Res A      80000

```

Continuation of WRAP-SIM DAT File for Example 1

```

**
WR CP-3 42000 irr 1975 0.1 WR-3
WS Res B 30000
WR CP-3 8888 WR-4
WS Res B 40000
**
WR CP-4 26000 mun 1984 2 0.35 2 WR-5
WS Res A 80000
**
WR CP-5 18000 mun 1952 2 2 WR-6
WS Res A 80000
**
IF CP-5 12000 0 1 WR-7
**
** Reservoir Storage Volume versus Surface Area Tables
**
SV Res A 0 825 2980 8640 22100 42700 73700 89600
SA 0 112 327 920 1760 2480 3750 4930
**
SV Res B 0 740 2680 7780 19800 38400 52900
SA 0 100 298 832 1580 2230 2690
**
** Drought Indices
**
DI 1 -1
IS 5 0 60000 108000 108001 120000
IP 50 100 100 120 120
**
DI 2 1 Res A
IS 4 0 20000 20001 81000
IP 80 80 100 100
**
** ! ! ! ! ! ! ! ! ! !
**3456789012345678901234567890123456789012345678901234567890123456789012
** 1 2 3 4 5 6 7
ED

```

WRAP-SIM FLO File for Example 1

```

** Example 1 - WRAP-SIM Input File Exam1H.FLO
** Example 1 from Appendix C of Reference Manual
**
** Naturalized Monthly Streamflows in acre-feet
**
IN CP-2 2015 10800 12500 8100 7620 9610 1200 850 2540 9520 1850 1760 7200
IN CP-3 2015 5200 6280 3750 3970 4450 750 1090 2160 4670 915 850 3490
IN CP-5 2015 19400 24600 14200 15200 18400 2640 2290 6240 21800 3780 3720 13900
**
IN CP-2 2016 6250 8140 4190 7280 6930 1390 725 545 942 1890 4910 5740
IN CP-3 2016 2180 4320 3760 2350 3760 870 915 296 1020 2250 4870 3190
IN CP-5 2016 11200 17800 10620 14500 15400 2930 1910 1290 2300 5190 12800 13700
**
IN CP-2 2017 7680 6590 5570 5230 6180 1280 1670 1050 7890 8670 6210 5360
IN CP-3 2017 3820 3540 2190 2310 3290 657 845 840 3970 4230 3540 2870
IN CP-5 2017 15400 13900 18300 9780 12600 2560 3420 2650 15400 17400 12700 11800

```

WRAP-SIM EVA File for Example 1

```

** Example 1 - WRAP-SIM Input File Exam1H.EVA
** Example 1 from Appendix C of Reference Manual
**
** Net Evaporation-Precipitation Rates in Inches
**
EV CP-2 2015 3.2 2.8 3.1 -1.6 -3.7 1.9 4.3 3.9 2.5 1.9 1.6 2.9
EV CP-2 2016 2.5 1.7 -4.9 -0.9 -2.1 0.7 3.5 2.8 3.1 2.5 0.9 2.6
EV CP-2 2017 2.9 2.1 -1.5 -2.8 -2.6 -0.2 2.7 -1.4 2.2 2.1 2.0 1.9

```

WRAP-SIM DIS File for Example 1

```

** Example 1 - WRAP-SIM Input File Exam1H.DIS
** Example 1 from Appendix C of Reference Manual
**
** Flow Distribution Information
**
FD CP-4 CP-5 2 CP-2 CP-3
FD CP-1 CP-2
**
WP CP-1 225 74 31
WP CP-2 398 69 31
WP CP-3 194
WP CP-4 650
WP CP-5 715
ED

```

TABLES Input File for Example 1

```

COMM TABLES Input File Exam1.TIN
COMM Example 1 from Appendix C of Reference Manual
PAGE
2REL
2FRE 1
2FRE 2
2FRE 3
2FRE 4 0 2
IDEN CP-2 CP-3
2FRQ 3 0 7 CP-5 200,2000,5000,8000,10000,15000,20000,
2SBA
ENDF

```

TABLES Output File for Example 1

```

*****
**
**          Water Rights Analysis Package          **
**                   TABLES                   **
**                   October 2017 Version        **
**
*****

```

Example 1 - WRAP-SIM Input File Exam1.DAT
 Example 1 from Appendix C of Reference Manual

The program WRAP-SIM output file contains simulation results for:
 7 water rights
 5 control points
 0 reservoirs
 for a period-of-analysis of 3 years beginning in 2015.

Program TABLES input file name: Exam1.TIN
 Program TABLES output file name: Exam1.TOU

Root of SIM input and output file names: Exam1

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET	MEAN	*RELIABILITY*		+++++++ PERCENTAGE OF MONTHS ++++++							----- PERCENTAGE OF YEARS -----						
	DIVERSION (AC-FT/YR)	SHORTAGE (AC-FT/YR)	PERIOD VOLUME (%)	(%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%
CP-1	1200.0	710.07	33.33	40.83	33.3	33.3	41.7	41.7	41.7	50.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
CP-3	42000.0	7336.29	66.67	82.53	66.7	66.7	75.0	75.0	83.3	83.3	100.0	33.3	33.3	33.3	33.3	66.7	100.0	100.0
CP-4	26000.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CP-5	18000.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	87200.0	8046.36	90.77															

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP-1	4416.5	2601.	545.0	609.8	674.6	825.0	1006.8	1760.0	4519.	5033.	5548.	6421.	7732.	9745.
CP-2	5162.8	3314.	545.0	609.8	674.6	825.0	1006.8	1760.0	5038.	5740.	6454.	7680.	9556.	12500.
CP-3	2762.7	1572.	296.0	426.0	555.9	731.4	843.0	1020.0	2274.	3190.	3540.	3970.	4750.	6280.
CP-4	9546.4	5747.	1081.7	1339.6	1597.6	2073.6	2233.6	3213.8	9638.	11394.	12235.	13600.	17079.	22023.
CP-5	10881.1	6598.	1290.0	1513.2	1736.4	2214.0	2456.0	3720.0	10852.	12700.	13900.	15400.	18800.	24600.

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP-1	4375.6	2608.	545.0	609.8	674.6	825.0	1006.8	1760.0	4519.	5033.	5548.	6421.	7600.	9745.
CP-2	4751.8	2977.	0.0	0.0	0.0	0.0	1018.7	2682.6	3807.	4692.	5691.	7010.	8780.	11516.
CP-3	493.7	1450.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	3606.	5748.
CP-4	5302.0	4720.	385.8	391.2	396.5	591.4	911.5	1617.8	1965.	4261.	5615.	8916.	12826.	19109.
CP-5	6531.7	5555.	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	3714.	6724.	7275.	11066.	14946.	21589.

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP-1	2981.4	3173.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2784.	4679.	5648.	7281.	9745.
CP-2	3529.7	3818.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2784.	5453.	7010.	8780.	11516.
CP-3	493.7	1450.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	3606.	5748.
CP-4	4773.8	5181.	0.0	0.0	0.0	0.0	0.0	0.0	970.	4261.	5615.	8916.	12826.	19109.
CP-5	5492.8	5510.	0.0	0.0	0.0	0.0	0.0	0.0	2714.	5724.	6275.	9866.	13826.	20389.

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP-2	76936.	4973.	62010.	62537.	63064.	66029.	70227.	75835.	78710.	80000.	80000.	80000.	80000.	80000.
CP-3	16284.	12057.	291.	462.	632.	830.	1131.	8303.	11984.	14826.	17707.	23803.	40000.	40000.
Total	93220.	15454.	64759.	65023.	65286.	67822.	74457.	84759.	89790.	93203.	97707.	103203.	120000.	120000.

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS FOR CONTROL POINT CP-5

FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)
200.0	66.67	2000.0	58.33	5000.0	52.78	8000.0	30.56	10000.0	22.22	15000.0	5.56	20000.0	2.78

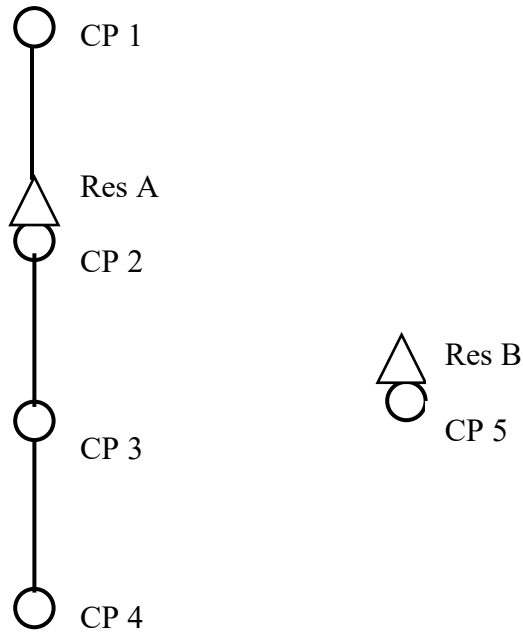
ANNUAL SUMMARY TABLE FOR THE RIVER BASIN

Note: For naturalized streamflow and unappropriated flow, the quantities shown represent the maximum flow at any control point in a given month, based on comparing all control points. All other quantities shown are the sum of the values for all the control points.

YEAR	NATURALIZED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	UNAPPROPRIATED FLOW (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2015	146170.0	13396.0	73154.1	84933.1	95181.7	10228.3	87200.0	86480.0	720.0
2016	109640.0	12553.6	71755.2	50464.7	82921.8	3506.9	87200.0	78125.7	9074.3
2017	135910.0	12043.5	88504.2	62930.0	94918.9	2660.1	87200.0	72855.2	14344.7
MEAN	130573.3	12664.4	77804.5	66109.2	91007.5	5465.1	87200.0	79153.6	8046.4

WRAP-SIM and TABLES Example 2

The *SIM* input data for Example 2 are stored in files, with filenames exam2.DAT, exam2.FLO, and exam2.EVA, which are printed on the following pages. *TABLES* input and output files (filenames exam2.TIN and exam2.TOU) are also shown. A two-year 2015-2016 hydrologic period-of-analysis is adopted. A system schematic is provided below. Control point CP 5 is located in a separate river basin from the other control points. Very simple numbers are used in this example to facilitate manual tracking of the simulation computations. Comment ****** records inserted in the exam2.DAT file describe the various groups of records.



System Schematic for Example 2

WRAP-SIM DAT File for Example 2

```

T1 WRAP-SIM Input File Exam2.DAT
T2 Example 2 from Appendix C of Reference Manual
**
** The default DAT, INF, EVA input files and OUT and MSS output files
** are used, but there is no DIS file.
**
JD      2      2015      1      -1      -1
**
** The -1's on the JD record result in output for all water rights and control
** points. The following RO record results in output for the two reservoirs.
**
RO      2      Res A      Res B
**
** Constant use factors distribute an annual diversion uniformly over the year.
** Since this is the model default, the following UC records are not required.
**
UC const      1      1      1      1      1      1
UC            1      1      1      1      1      1
**

```

```

** RF records allow return flow factors to vary over the 12 months of the year.
**
RF rflow      0.2      0.2      0.2      0.0      0.0      0.0
RF            0.3      0.3      0.3      0.25     0.25     0.25
**
** Loss CL factors of 0.25 and 0.3 are input in field 10 of the CP records
** for CP1 and CP2. The watershed area of 1,000 acres entered in field 9
** for CP2 is used in determining the adjusted net evap-precip for RES1.
** Field 8 indicates there are no EV records for CP1, CP3, and CP4.
**
CP  CP1      CP2                NONE          0.25
CP  CP2      CP3                1000.        0.30
CP  CP3      CP4                none
CP  CP4      OUT                zero
CP  CP5      OUT                CP2
**
** An inflow of 20 acre-feet/month enters the river system at CP1.
**
CI  CP1      20      20      20      20      20      20
CI  CP1      20      20      20      20      20      20
**
** Instream flow requirement IF1 sets a minimum regulated flow target of
** 70 ac-ft/month at CP3. With a priority number of 1900, IF1 is senior
** to all of the other rights except IF4.
**
IF  CP3      840  const  1900      2      IF1
**
** Return flow options 4 and 1 are adopted for water rights WR1 and WR2a.
**
WR  CP1      360  const  1985      3  rflow          WR1
WR  CP2      840  const  1980      0.2          WR2a
WS Res A    200  0.1      1      0.      400
**
** WR2a refills storage in reservoir Res A to 200 ac-ft with a 1980 priority.
** WR2b fills Res A to full capacity of 500 ac-ft, subject to limits imposed
** by the MS records, with a priority junior to all other rights.
**
WR  CP2      0  const  3000          WR2b
WS Res A    500          400
**
** Releases from Res A are made, if necessary, to meet a instream flow target
** of 30 ac-ft/month set by IF2. RESA passes inflows but does not release
** from storage for the IF1 target of 70 ac-ft/month.
**
IF  CP3      360  const  2000      3      IF2
WS Res A    500          400
**
** The final unappropriated flows are based on the IF1 instream flow
** requirement of 70 ac-ft/month at CP3, which is repeated as IF3 with a
** priority junior to all rights except the WR2b reservoir refilling right.
**
IF  CP3      840  const  2100      2      IF3
**
** A minimum flow at CP5 must be maintained of 50 percent of the CP5 naturalized
** streamflow. The minimum flow at CP5 must also be at least 2 percent of the
** regulated flow at CP4. This is the most senior right in the model.
**
IF  CP5                1800      2      IF4
TO  1      0.5          CP5
TO  2      0.02      MAX          CP4
**
** Res B is located at CP5 and is filled from streamflow at CP4 as well as CP5.
** WR3a includes both storage in Res B and a 20 ac-ft/month diversion at CP5.
** WR3b allows filling of Res B at CP5 by depleting streamflows from CP4.
** The CP4 streamflow depletion has both monthly and annual limits.
**
WR  CP5      240  const  8888          WR3a
WS Res B    100  0.1      1      0.0
WR  CP5      0  const  9999          WR3b
WS Res B    100
SO                350  CP4
ML  5      0      0      5      15      15      200      200      200      200      200      200

```

```

**
** A seasonal rule curve operating plan is in effect for reservoir Res A.
** Storage is limited to 400 ac-ft from October through March and limited
** to 500 ac-ft from April through September.
**
MS Res A 400,400,400,500,500,500,500,500,400,400,400
**
** The hydrology (IN and EV) records are in files Exam5.FLO and Exam5.EVA.
**
ED

```

WRAP-SIM FLO File for Example 2

```

** WRAP-SIM Input File Exam2.FLO
** Example 2 from Appendix C of Reference Manual
**
** Naturalized Streamflows
** The flows for 2015 illustrate the optional comma delimited format.
**
IN CP1 ,2015 60,60,60,80,80,80,30,30,30,90,90,90,
IN CP2 ,2015 100,100,100,120,120,120,50,50,50,150,150,150,
IN CP3 ,2015 130,130,130,160,160,160,80,80,80,200,200,200,
IN CP4 ,2015 190,190,190,220,220,220,140,140,140,260,260,260,
IN CP5 ,2015 10,10,10,10,10,10,10,10,10,10,10,10,
**
IN CP1 2016 60 60 60 0 0 0 120 120 120 60 60 60
IN CP2 2016 100 100 100 0 0 0 200 200 200 100 100 100
IN CP3 2016 130 130 130 130 0 0 0 260 260 260 130 130 130
IN CP4 2016 190 190 190 190 60 60 60 320 320 320 190 190 190
IN CP5 2016 10 10 10 10 10 10 10 10 10 10 10 10 10

```

WRAP-SIM EVA File for Example 2

```

** WRAP-SIM Input File Exam2.EVA
** Example 2 from Appendix C of WRAP Reference Manual
** Net Evaporation-Precipitation Rates
**
EV CP2 2015 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
EV CP2 2016 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5

```

TABLES Input File for Example 2

```

COMM TABLES Input File Exam2.TIN
COMM Example 2 from Appendix C of Reference Manual
2SCP
2REL 1
2RES 0 0 2 Res A Res B
2RES 500 100
ENDF

```

TABLES Output File for Example 2

ANNUAL SUMMARY TABLE FOR CONTROL POINT CPI

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2015	780.0	670.0	96.2	0.0	350.0	0.0	0.0	350.0	10.0
2016	720.0	690.0	84.0	0.0	270.0	0.0	0.0	270.0	90.0
MEAN	750.0	680.0	90.1	0.0	310.0	0.0	0.0	310.0	50.0

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP2

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2015	1260.0	119.3	72.1	64.5	1122.7	400.0	282.7	840.0	0.0
2016	1200.0	159.2	90.7	67.5	1168.5	400.0	245.8	840.0	0.0
MEAN	1230.0	139.3	81.4	66.0	1145.6	400.0	264.2	840.0	0.0

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP3

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2015	1710.0	1079.5	239.5	168.0	0.0	0.0	0.0	0.0	0.0
2016	1560.0	999.5	279.5	184.5	0.0	0.0	0.0	0.0	0.0
MEAN	1635.0	1039.5	259.5	176.2	0.0	0.0	0.0	0.0	0.0

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP4

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2015	2430.0	1573.0	1573.0	0.0	226.5	0.0	0.0	0.0	0.0
2016	2280.0	1489.4	1489.4	0.0	230.1	0.0	0.0	0.0	0.0
MEAN	2355.0	1531.2	1531.2	0.0	228.3	0.0	0.0	0.0	0.0

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP5

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2015	120.0	61.2	0.0	0.0	58.8	100.0	45.2	240.0	0.0
2016	120.0	64.8	0.0	0.0	55.2	100.0	45.2	240.0	0.0
MEAN	120.0	63.0	0.0	0.0	57.0	100.0	45.2	240.0	0.0

RELIABILITY SUMMARY FOR SELECTED WATER RIGHTS

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* ++++++ PERCENTAGE OF MONTHS ++++++ ----- PERCENTAGE OF YEARS ----- WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT														
			PERIOD	VOLUME	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%
WR2a	840.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
WR1	360.0	50.00	75.00	86.11	75.0	75.0	75.0	87.5	87.5	87.5	87.5	0.0	0.0	50.0	50.0	100.0	100.0
WR3a	240.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	1440.0	50.00		96.53													

END-OF-PERIOD RESERVOIR STORAGE AS A PERCENTAGE OF CAPACITY

Percentage = 100% * (S - C2) / (C1 - C2) where
 S = end-of-month storage
 C1,C2 = user defined top and bottom of storage zone

YEAR	MONTH	MEAN	Res A	Res B
2015	1	82.50	80.00	85.00
2015	2	73.00	80.00	66.00
2015	3	64.00	80.00	48.00
2015	4	59.70	83.40	36.00
2015	5	60.30	86.60	34.00
2015	6	61.30	89.60	33.00
2015	7	89.20	78.40	100.00
2015	8	83.90	67.80	100.00
2015	9	78.90	57.80	100.00
2015	10	84.80	69.60	100.00
2015	11	90.00	80.00	100.00
2015	12	90.00	80.00	100.00
2016	1	82.50	80.00	85.00
2016	2	73.00	80.00	66.00
2016	3	64.00	80.00	48.00
2016	4	48.40	60.80	36.00
2016	5	38.30	42.60	34.00
2016	6	29.20	25.40	33.00
2016	7	74.50	49.00	100.00
2016	8	85.60	71.20	100.00
2016	9	95.90	91.80	100.00
2016	10	90.00	80.00	100.00
2016	11	90.00	80.00	100.00
2016	12	90.00	80.00	100.00

RESERVOIR STORAGE DRAWDOWN DURATION

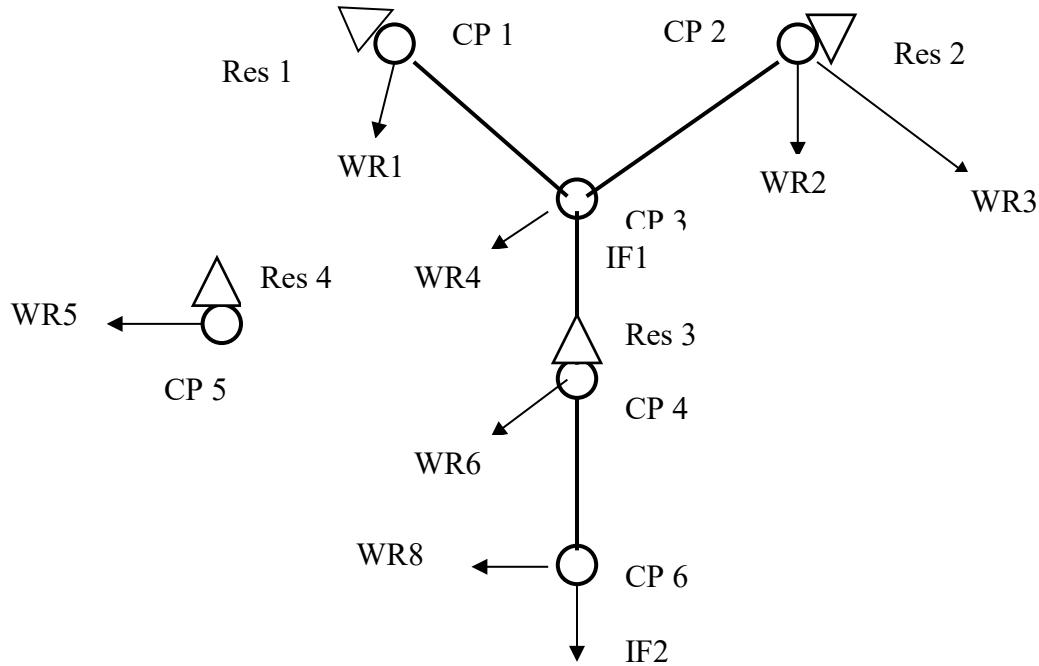
NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	NUMBER OF PERIODS WITH DRAWDOWNS EQUALING OR EXCEEDING PERCENT OF ZONE STORAGE CAPACITY								
				0%	2%	5%	10%	25%	50%	75%	90%	100%
Res A	365.42	0.	500.	24.	24.	24.	23.	8.	3.	0.	0.	0.
Res B	75.17	0.	100.	24.	12.	12.	12.	10.	8.	0.	0.	0.

RESERVOIR STORAGE RELIABILITY

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING PERCENTAGE OF STORAGE CAPACITY								
				100%	98%	95%	90%	75%	50%	25%	10%	>0%
Res A	365.42	0.	500.	0.0	0.0	0.0	4.2	66.7	87.5	100.0	100.0	100.0
Res B	75.17	0.	100.	50.0	50.0	50.0	50.0	58.3	66.7	100.0	100.0	100.0

Example 3 Featuring Hydropower and Multiple-Reservoir System Operations

The *WRAP-SIM* input data for Example 3 are stored in one file named Exam3.DAT which is reproduced later. *TABLES* input and output files (filenames Exam3.TIN and Exam3.TOU) are also shown. As indicated by the schematic below, the system configuration includes five control points located in one river basin and another control point located in another river basin. There are eleven water rights and four reservoirs. Very simple numbers are used in this example to facilitate manual tracking of the simulation computations.



System Schematic for Example 3

Hydrology for Example 3

A 2008-2009 hydrologic period-of-analysis is used. Naturalized stream flows are provided on *IN* records for each month of the two-year simulation at each of the six control points. The naturalized flows are in acre-feet/month at all of the control points except CP5, which are in units of thousand cubic meters per month. A conversion factor of 0.811 ac-ft/1,000 m³ is provided on the *CP* record for CP5. The file and sequencing options for the *IN* and *EV* are defined in *JO* record field 2.

Reservoir net evaporation-precipitation rates are entered on *EV* records for control points CP1 and CP2. The data for CP1 are also used at CP4 and CP5 (*CP* record field 9). The rates are in units of feet/month for CP1 and inches/month at CP2. The *CP* record for CP2 includes a conversion of 0.0833 foot/inch. The *NONE* on the *CP* records for CP3 and CP6 indicate that no evaporation-precipitation data are provided or required.

Example 3 Water Rights Listed in Priority Order

Water Right ID	Water Right Type	Control Point ID	Return Flow Location	Diversion Target (ac-ft/yr)	Instream Flow (ac-ft/yr)	Primary Reservoir Identifier	Reservoir Capacity (ac-ft)	Secondary Reservoir Identifier
IF2	1	CP6			240			
IF1	1	CP3			120			
WR1	1	CP1	CP3	360		Res1	200	
WR2	1	CP2	CP3	60		Res2	50	
WR4	2	CP3		720				Res1 Res2
WR6	1	CP4		120				Res3
WR5a	2	CP5		600				Res3 Res4
WR5b	1	CP5				Res4	200	
WR3	1	CP2	CP3	180		Res2	250	
WR8	4	CP6	CP3	varies				Res1 Res2 Res3
WR7	5	CP4		*		Res3	300	

* Permitted annual energy target for WR7 is 12,000 kilowatt-hours.

Example 3 Reservoir Storage Capacity

Reservoir Identifier	Primary or Secondary (P or S)	Water Right Identifier	Storage Capacity to Refill (ac-ft)	Inactive Pool Capacity (ac-ft)	Capacity at Top of	
					Zone 1	Zone 2
Res1	P	WR1	200	10		
	S	WR4		10	200	200
	S	WR8		10	200	200
Res2	P	WR2	50	25		
	P	WR3	110	25		
	S	WR4		25	250	150
	S	WR8		25	250	125
Res3	P	WR6		30		
	P	WR9	300	30		
	S	WR4		30	300	165
	S	WR5b		150	300	300
	S	WR8		30	300	165
Res4	S	WR5a			200	100
	P	WR5b	200			

Volume versus Area Relationships for the Example 3 Reservoirs

A storage volume versus water surface area relationship is required for each of the four reservoirs for use in the evaporation computations. A table of storage volume, in acre-feet, versus area, in acres, is provided on *SV* and *SA* records for reservoir Res4.

The storage-volume relationships for the other three reservoirs are provided by the alternative option of entering the coefficients for Equation 4.1 in fields 4, 5, and 6 of the *WS* record. With values of 0.1, 1.0, and 0.0 for coefficients *a*, *b*, and *c*, respectively, for each of these reservoirs, Equation 4.1 reduces to:

$$\text{area in acres} = 0.1 (\text{storage volume in acre-feet})$$

Water Rights for Example 3

Information associated with each water right is summarized in the tables on the next page. Diversion, instream flow, and hydropower requirements are provided in the first table. Reservoir storage capacities are tabulated in the second table.

Water Rights IF1 and IF2. - Water rights IF1 and IF2 are instream flow requirements at control points CP3 and CP6, respectively, of 120 ac-ft/year (10 ac-ft/month) and 240 ac-ft/year (20 ac-ft/month). With priority numbers of 191805 (May 1918) and 191803 (March 1918), these are the two most senior rights in the system.

Water Right WR1. - Water right WR1 located at control point CP1 has a permitted diversion of 360 ac-ft/yr, priority number of 192602 representing February 1926, and same-month return flow of 20% reentering the river at CP3. The annual diversion amount is converted to monthly diversions using the default constant monthly use factors. WR1 is a type 1 right with RES1 being its primary and only reservoir. Reservoir Res1 can be filled to a capacity of 200 ac-ft and supply water for the WR1 diversion until the storage level drops below the inactive pool capacity of 10 ac-ft. The volume-area relationship coefficients must be entered with WR1 since this is the first time Res1 is cited but do not have to be repeated on subsequent Res1 *WS* records.

Water Rights WR2 and WR3. - Res2 is the primary (and only) reservoir for both WR2 and WR3, which can refill it to total cumulative capacities of 50 and 250 ac-ft, respectively. WR2 and WR3 have permitted annual diversion amounts of 60 and 180 ac-ft/yr, respectively, which are met by CP2 inflows as long as yet unappropriated stream flow is available and then withdrawals from Res2 as long as the storage is above the inactive pool capacity of 25 ac-ft. WR3 is junior to WR2. Several other rights at other locations have priorities which fall between WR2 and WR3.

Water Right WR4. - WR4 is a type 2 right with two secondary reservoirs but no primary reservoir. The WR4 diversion target is 720 ac-ft/yr or 60 ac-ft/month at CP3. Return flows of 40% the diversion amount reenter the river at the default next downstream control point.

The WR4 diversion target is met first by available stream flow at CP3 and then, as necessary, by releases from reservoirs Res1 and Res2. WR4 is denoted a type 2 right since (unlike a type 1 right) it does not refill reservoir storage and (like a type 1 but unlike a type 3 right) it

makes releases from Res1 and Res2 only if sufficient stream flow is not available at CP3 for the diversion.

Multiple-reservoir system operations are based on balancing the storage, as a percent of zone capacity, in each reservoir. *WRAP-SIM* computes a ranking index for each reservoir using Equation 4.6 from Chapter 4.

$$\text{rank index} = (\text{multiplier factor}) \left[\frac{\text{storage content in zone}}{\text{storage capacity of zone}} \right] + \text{addition factor} \quad (4.6)$$

The release is made from the reservoir with the greatest value for the rank index. The reservoir zones are defined by Figure 4.2. Zone 1 must be empty in all the reservoirs in the system in order for releases to be made from zone 2 of any of the reservoirs.

The weighting factors used in the above formula are entered for each reservoir on the *OR* records. Weighting factors of either 1.0 or zero are used for the two zones of all reservoirs in the example. Since only the relative magnitude between reservoirs matters, replacing the 1.0's with any positive constant number will yield the same result. Since the zeroes are assigned to zones with zero storage capacity, any other number will yield the same result.

For water right WR4, the Res2 cumulative storage capacities at the top of inactive zone, active zone 2, and active zone 1 are 25 ac-ft, 125 ac-ft, and 250 ac-ft. Thus, zones 1 and 2 have capacities of 125 ac-ft (250-125), and 100 ac-ft (125-25), respectively. Res1 has cumulative storage capacities at the top of inactive zone, active zone 2, and active zone 1 of 10, 200, and 200 ac-ft, respectively. Since *WS* record field 3 and *OR* record field 3 both contain values of 200 ac-ft, Res1 zone 1 contains zero storage capacity. In order for a release to be made from Res1, the storage contents of Res2 must be below 125 ac-ft.

Water Rights WR5a and WR5b. Since multiple-reservoir release decisions are pertinent only to secondary reservoirs and storage capacity can be replenished only in a primary reservoir, WR5 is treated as two separate water rights WR5a and WR5b. Water right WR5a has a diversion of 50 ac-ft/month (600 ac-ft/yr.) located at CP5 which is met by available stream flow at CP5 supplemented by releases from reservoirs Res3 and Res4. WR5b refills storage in Res4 from available stream flow. WR5b is assigned a priority junior to WR5a so that the Res4 storage capacity is refilled after, rather than before, the WR5a diversion and associated release decisions are completed.

With the exception of Res4, the reservoirs are full at the beginning of the simulation on 1 January 2008. The storage content of Res4 is 100 ac-ft when the simulation begins.

The WR5a diversion is supplied by water from the following sources in the order listed:

- (1) stream flows at CP5 (inflows to Res4) until the stream flow is depleted
- (2) releases or withdrawals from Res4 until the reservoir is emptied to less than half of its storage capacity
- (3) releases and withdrawals from both Res3 and Res4 until Res3 is emptied to less than half of its storage capacity and Res4 is empty

When both Res3 and Res4 are supplying water, release decisions are based on balancing the percent full (or percent depleted) of specified zones consisting of the lower half of Res4 and the upper half of Res3. Shortages occur if the indicated stream flow and reservoir storage is insufficient to meet the permitted diversion. This WR5a multiple-reservoir operating policy is defined in the *WRAP-SIM* input file as follows. Active pool zone 1 (Figure 4-1) in Res4 has a capacity of 100 ac-ft since the total cumulative capacities at the top of zone 1 is 200 ac-ft and at the top of zone 2 (bottom of zone 1) is 100 ac-ft. The inactive pool has zero storage. Thus, the Res4 storage capacity is divided in half, with 100 ac-ft in the upper zone 1 and 100 ac-ft in the lower zone 2. For WR5a, reservoir Res3 has cumulative capacities at the top of inactive pool, active pool zone 2, and zone 1 of 150 ac-ft, 300 ac-ft, and 300 ac-ft. Thus, zone 1 in Res3 has zero capacity. Res4 must be half empty before water is taken from Res3. Likewise, water is not withdrawn from Res3 for WR5 if the storage content of Res3 falls below 150 ac-ft.

CP5 is located in a different river basin than the other control points. Water withdrawn from Res3 and CP4 is conveyed by pipeline (or some means other than the gravity flow in river channels) to the WR5a diversion site at CP5. Consequently, a negative one is entered in field 6 of the *OR* record. A negative integer in this field has the effect of acting as a switch to allow a reservoir to release to a diversion with a control point location which is not downstream of the reservoir. Field 11 of the *WS* record is also flagged with a negative integer indicating that the WR5a releases from Res3 do not pass through the hydroelectric power plant associated with water right WR7.

Water Right WR6. - WR6 diverts 120 ac-ft/yr at CP4 from available stream flow and Res3 storage. Since WR6 is not permitted to refill storage, a type 2 right is specified.

Water Right WR7. - WR7 generates hydroelectric power and refills storage in Res3. With a POWFCT value of 1.0237, the energy units are kilowatt-hours. The permitted firm energy is a constant 12,000 kW-hr. The cumulative total storage capacity and inactive pool (bottom of power pool) capacity are 300 ac-ft and 30 ac-ft respectively. The tailwater elevation is 5.0 feet, and the plant efficiency is 85%. All flows through control point CP4 can be diverted through the hydroelectric turbines except for the lakeside withdrawals from Res3 for WR5. WR7 is a type 5 right with Res3 as the primary (and only) reservoir.

Res3 storage versus elevation data, used to compute the head term of the power equation, are provided on *PV* and *PE* records. The elevation is assumed to vary linearly from zero to 100 feet as storage varies from zero to 300 ac-ft.

Water Right WR8. - WR8 is a type 3 diversion right with the permitted diversion amount being supplied only by reservoirs Res1, Res2, and Res3 without appropriating stream flows at CP6. The diversion target is a function of month of the year (*WR* record field 4 and *UC* records). The permitted diversion is zero during the months from September through April (*UC* records). During the remaining four months, the permitted diversion is ac-ft/month.

WRAP-SIM Input File for Example 3

```

T1 WRAP-SIM Input File Exam3.DAT
T2 Example 3 from Appendix C of Reference Manual
**
**      ! 1      ! 2      ! 3      ! 4      ! 5      ! 6      ! 7      ! 8
**34567890123456789012345678901234567890123456789012345678901234567890
**      !      !      !      !      !      !      !      !      !
**
JD      2      2008      1      -1      -1
JO      4
XL                                  1.0237
RO      1      RES3
**
** Monthly Use Factors
**
UC      MUN      0.06      0.06      0.07      0.07      0.08      0.10
UC      0.13      0.12      0.09      0.08      0.08      0.06
UC IRRIG      0      0      0      0      0.25      0.25
UC      0.25      0.25      0      0      0      0
**
** Control Point Records
**
CP      CP1      CP3
CP      CP2      CP3      0.08333
CP      CP3      CP4      NONE
CP      CP4      CP6      CP1
CP      CP5      OUT      0.811      CP1
CP      CP6      OUT      NONE
**
** Water Rights and Associated Reservoirs
**
** Water Right IF2
IF      CP6      240      191803      IF2
** Water Right IF1
IF      CP3      120      191805      IF1
** Water Right WR1
WR      CP1      360.      192602      1      .2      WR1
WS      RES1      200.      .1      1.      0.      10.
** Water Right WR2
WR      CP2      60.      IRRIG      193908      1      .2      WR2
WS      RES2      50.      .1      1.      0.      25.
** Water Right WR3
WR      CP2      180.      196506      1      .2      WR3
WS      RES2      250.      .1      1.      0.      25.
** Water Right WR4
WR      CP3      720.      MUN      195207      2      0.4      WR4
WS      RES2      250.      25.
OR      125.      1      1
WS      RES1      200.      10.
OR      200.      0      1
** Water Rights WR5a and WR5b
WR      CP5      0.      196213      1      WR5b
WS      RES4      200.      -1      100.
WR      CP5      600.      196212      2      WR5a
WS      RES4      200.      -1
OR      100.      1      1      -1
WS      RES3      300.      .1      1.      0.      150.
OR      CP4      300.      1      1      -1
** Water Right WR6
WR      CP4      120.      195704      2      WR6
WS      RES3      300.      .1      1.      0.      30.
** Water Right WR7
WR      CP4      12000.      197801      5      WR7
WS      RES3      300.      30.
HP      0.85      5.

```


Continuation of WRAP-SIM Input File for Example 3

```

** Water Right WR8 -----
WR  CP6  400.  IRRIG  197412  3  2                               WR8
WS  RES2  250.                                     25.
OR  125.      1      1
WS  RES1  200.                                     10.
OR  200.      0      1
WS  RES3  300.      .1  1.      0.      30.
OR  165.      1      1
**
** Storage versus Area Table for Reservoir RES4
**
SV  RES4  0.  200.
SA  0.  20.
**
** Storage versus Elevation Table for Reservoir RES3
**
PV  RES3  0.  300.
PE  0.  100.
**
ED
**
** Monthly Naturalized Streamflow
**
IN  CP1  2008  60  60  60  60  60  60  10  10  10  10  10  10
IN  CP1  2009  60  60  60  300  300  300  10  10  10  10  10  10
IN  CP2  2008  20  20  20  20  20  20  0  0  0  0  0  0
IN  CP2  2009  20  20  20  100  100  100  0  0  0  0  0  0
IN  CP3  2008  120  120  120  100  100  100  30  30  30  30  30  30
IN  CP3  2009  120  120  120  500  500  500  30  30  30  30  30  30
IN  CP4  2008  120  120  120  120  120  120  40  40  40  40  40  40
IN  CP4  2009  120  120  120  600  600  600  40  40  40  40  40  40
IN  CP5  2008  74  74  74  12.33  12.33  12.33  12.33  12.33  12.33  92.5  92.5  92.5
IN  CP5  2009  74  74  74  61.67  61.67  61.67  12.33  12.33  12.33  92.5  92.5  92.5
IN  CP6  2008  150  150  150  180  180  180  50  50  50  50  50  50
IN  CP6  2009  150  150  150  900  900  900  50  50  50  50  50  50
**
** Monthly Net Evaporation-Precipitation Depths
**
EV  CP1  2008  .5  .5  .5  .5  .5  .5  .5  .5  .5  .5  .5  .5
EV  CP1  2009  .5  .5  .5  .5  .5  .5  .5  .5  .5  .5  .5  .5
EV  CP2  2008  6.  6.  6.  6.  6.  6.  6.  6.  6.  6.  6.  6.  6.
EV  CP2  2009  6.  6.  6.  6.  6.  6.  6.  6.  6.  6.  6.  6.  6.

```

TABLES Input File for Example 3

```

COMM  TABLES Input File Exam3.TIN
COMM  Example 3
2REL
2REL      2  1
IDEN  RES3
2FRE  1
2FRE  2
2FRE  3
2FRE  4  0  4
IDEN  CP1  CP2  CP4  CP5
2REG  1  1  1
2UNA  1  1  0
ENDF

```

TABLES Output File for Example 3

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET	MEAN	*RELIABILITY*		PERCENTAGE OF MONTHS							PERCENTAGE OF YEARS						
	DIVERSION (AC-FT/YR)	SHORTAGE (AC-FT/YR)	PERIOD (%)	VOLUME (%)	WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT							PERCENTAGE OF TARGET DIVERSION AMOUNT						
					100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%
CP1	360.0	82.00	66.67	77.22	66.7	66.7	66.7	66.7	66.7	100.0	100.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0
CP2	240.0	67.83	58.33	71.74	58.3	62.5	62.5	62.5	66.7	66.7	66.7	0.0	0.0	0.0	0.0	0.0	100.0	100.0
CP3	720.0	165.52	62.50	77.01	62.5	66.7	66.7	66.7	70.8	79.2	100.0	0.0	0.0	0.0	0.0	50.0	100.0	100.0
CP4	120.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CP5	600.0	28.98	91.67	95.17	91.7	91.7	91.7	91.7	95.8	95.8	100.0	50.0	50.0	50.0	100.0	100.0	100.0	100.0
CP6	400.0	8.02	87.50	97.99	87.5	87.5	87.5	100.0	100.0	100.0	100.0	50.0	50.0	100.0	100.0	100.0	100.0	100.0
Total	2440.0	352.36		85.56														

RELIABILITY SUMMARY FOR SELECTED HYDROELECTRIC POWER PROJECTS

NAME	ENERGY	MEAN	*RELIABILITY*		PERCENTAGE OF MONTHS							PERCENTAGE OF YEARS						
	TARGET	SHORTAGE	PERIOD (%)	AMOUNT (%)	WITH ENERGY GENERATION EQUALING OR EXCEEDING PERCENTAGE OF TARGET							PERCENTAGE OF TARGET						
					100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%
RES3	12000.0	3093.51	70.83	74.22	70.8	70.8	70.8	70.8	70.8	75.0	100.0	0.0	0.0	0.0	0.0	50.0	100.0	100.0
Total	12000.0	3093.51		74.22														

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
CP1	65.0	94.	10.0	10.0	10.0	10.0	10.0	10.0	10.	60.	60.	60.	300.	300.
CP2	20.0	32.	0.0	0.0	0.0	0.0	0.0	0.0	0.	20.	20.	20.	100.	100.
CP3	120.0	152.	30.0	30.0	30.0	30.0	30.0	30.0	30.	100.	108.	120.	500.	500.
CP4	140.0	182.	40.0	40.0	40.0	40.0	40.0	40.0	40.	120.	120.	120.	600.	600.
CP5	43.8	28.	10.0	10.0	10.0	10.0	10.0	10.0	50.	60.	60.	75.	75.	75.
CP6	197.5	276.	50.0	50.0	50.0	50.0	50.0	50.0	50.	150.	150.	180.	900.	900.

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
CP1	45.1	74.	0.0	0.0	0.0	0.0	0.0	0.0	12.	20.	22.	65.	207.	260.
CP2	10.1	20.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	14.	58.	67.
CP3	51.5	88.	10.0	10.0	10.0	10.0	10.0	10.0	13.	13.	21.	30.	255.	314.
CP4	59.4	115.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2.	10.	100.	282.	408.
CP5	0.0	0.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
CP6	95.9	169.	10.0	10.0	10.0	10.0	10.0	23.3	33.	48.	49.	60.	492.	608.

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP1	22.4	73.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	2.	158.	260.
CP2	0.1	1.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	3.
CP3	25.5	84.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	2.	176.	304.
CP4	26.7	86.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	2.	189.	308.
CP5	0.0	0.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
CP6	78.0	168.	0.0	0.0	0.0	0.0	0.0	3.3	13.	28.	29.	40.	472.	588.

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP1	89.	86.	10.	10.	10.	10.	10.	10.	23.	55.	121.	200.	200.	200.
CP2	96.	87.	20.	21.	21.	22.	22.	24.	27.	53.	97.	179.	236.	243.
CP4	168.	110.	30.	30.	30.	30.	30.	30.	160.	197.	213.	300.	300.	300.
CP5	62.	33.	0.	0.	0.	5.	23.	30.	68.	72.	76.	84.	108.	114.
Total	415.	287.	64.	69.	75.	89.	101.	193.	264.	275.	514.	756.	844.	848.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	20.	20.	20.	20.	36.	50.	75.	24.	0.	0.	0.	0.	265.
2009	7.	7.	14.	128.	260.	260.	75.	65.	0.	0.	0.	0.	817.
MEAN	14.	14.	17.	74.	148.	155.	75.	45.	0.	0.	0.	0.	541.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	0.	0.	0.	14.	19.	67.	0.	11.	0.	0.	0.	0.	112.
2009	0.	0.	0.	0.	0.	0.	17.	62.	52.	0.	0.	0.	131.
MEAN	0.	0.	0.	7.	10.	34.	8.	37.	26.	0.	0.	0.	122.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	26.	26.	19.	13.	30.	78.	13.	10.	10.	10.	10.	10.	253.
2009	13.	13.	13.	187.	314.	300.	30.	73.	10.	10.	10.	10.	983.
MEAN	19.	19.	16.	100.	172.	189.	21.	42.	10.	10.	10.	10.	618.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	6.	6.	2.	16.	100.	100.	100.	84.	0.	0.	0.	0.	414.
2009	0.	0.	0.	0.	408.	404.	100.	100.	0.	0.	0.	0.	1012.
MEAN	3.	3.	1.	8.	254.	252.	100.	92.	0.	0.	0.	0.	713.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP5

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2009	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP6

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	48.	48.	44.	88.	60.	60.	10.	10.	53.	23.	23.	23.	491.
2009	49.	49.	52.	323.	608.	604.	10.	10.	10.	30.	32.	34.	1810.
MEAN	48.	48.	48.	206.	334.	332.	10.	10.	32.	26.	27.	29.	1151.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	6.	6.	2.	3.	0.	0.	0.	0.	0.	0.	0.	0.	17.
2009	0.	0.	0.	0.	260.	260.	0.	0.	0.	0.	0.	0.	520.
MEAN	3.	3.	1.	2.	130.	130.	0.	0.	0.	0.	0.	0.	268.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.	0.	0.	3.
2009	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	0.	0.	0.	2.	0.	0.	0.	0.	0.	0.	0.	0.	2.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	6.	6.	2.	3.	0.	0.	0.	0.	0.	0.	0.	0.	17.
2009	0.	0.	0.	0.	304.	290.	0.	0.	0.	0.	0.	0.	594.
MEAN	3.	3.	1.	2.	152.	145.	0.	0.	0.	0.	0.	0.	306.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	6.	6.	2.	16.	0.	0.	0.	0.	0.	0.	0.	0.	30.
2009	0.	0.	0.	0.	308.	304.	0.	0.	0.	0.	0.	0.	612.
MEAN	3.	3.	1.	8.	154.	152.	0.	0.	0.	0.	0.	0.	321.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP5

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2009	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP6

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	28.	28.	24.	68.	40.	40.	0.	0.	33.	3.	3.	3.	271.
2009	29.	29.	32.	303.	588.	584.	0.	0.	0.	10.	12.	14.	1600.
MEAN	28.	28.	28.	186.	314.	312.	0.	0.	17.	6.	7.	9.	936.

		REG CP1	REG CP2	REG CP3	REG CP4	REG CP5	REG CP6	UNA CP1	UNA CP2	UNA CP3	UNA CP4	UNA CP5	UNA CP6
2008	1	20.00	0.00	25.80	5.98	0.00	48.08	5.98	0.00	5.98	5.98	0.00	28.08
2008	2	20.00	0.00	25.80	5.98	0.00	48.08	5.98	0.00	5.98	5.98	0.00	28.08
2008	3	20.00	0.00	18.60	1.66	0.00	43.76	1.66	0.00	1.66	1.66	0.00	23.76
2008	4	20.00	14.40	13.00	16.06	0.00	88.16	3.00	3.00	3.00	16.06	0.00	68.16
2008	5	36.10	19.13	29.63	100.00	0.00	60.00	0.00	0.00	0.00	0.00	0.00	40.00
2008	6	50.50	66.96	77.46	100.00	0.00	60.00	0.00	0.00	0.00	0.00	0.00	40.00
2008	7	74.60	0.00	13.00	100.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	8	23.80	11.32	10.00	83.96	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	9	0.00	0.00	10.00	0.00	0.00	53.36	0.00	0.00	0.00	0.00	0.00	33.36
2008	10	0.00	0.00	10.00	0.00	0.00	23.26	0.00	0.00	0.00	0.00	0.00	3.26
2008	11	0.00	0.00	10.00	0.00	0.00	23.26	0.00	0.00	0.00	0.00	0.00	3.26
2008	12	0.00	0.00	10.00	0.00	0.00	23.26	0.00	0.00	0.00	0.00	0.00	3.26
2009	1	7.20	0.00	12.87	0.00	0.00	48.65	0.00	0.00	0.00	0.00	0.00	28.65
2009	2	7.20	0.00	13.00	0.00	0.00	48.78	0.00	0.00	0.00	0.00	0.00	28.78
2009	3	14.40	0.00	13.00	0.00	0.00	51.66	0.00	0.00	0.00	0.00	0.00	31.66
2009	4	128.48	0.00	187.08	0.00	0.00	323.31	0.00	0.00	0.00	0.00	0.00	303.31
2009	5	260.00	0.00	314.40	408.33	0.00	608.33	260.00	0.00	304.40	308.33	0.00	588.33
2009	6	260.00	0.00	300.00	403.80	0.00	603.80	260.00	0.00	290.00	303.80	0.00	583.80
2009	7	74.60	16.63	29.63	100.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	8	65.25	62.42	73.27	100.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	9	0.00	52.43	10.00	0.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	10	0.00	0.00	10.00	0.00	0.00	29.74	0.00	0.00	0.00	0.00	0.00	9.74
2009	11	0.00	0.00	10.00	0.00	0.00	31.59	0.00	0.00	0.00	0.00	0.00	11.59
2009	12	0.00	0.00	10.00	0.00	0.00	34.06	0.00	0.00	0.00	0.00	0.00	14.06

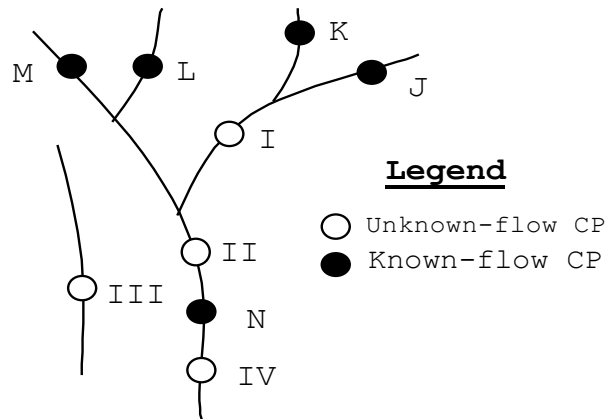
Example 4 Featuring Flow Distribution DIS File *FD*, *FC*, and *WP* Records

Example 4 focuses solely on distributing monthly naturalized stream flows from primary to secondary control points. A primary control point by definition is a site for which period-of-analysis sequences of monthly stream flows are provided on *IN* records in a FLO, DSS, or DAT input file. Flows at all other control points, called secondary control points, are computed within the *SIM* simulation from flows read from *IN* records and parameters from DAT file *CP* records and/or DIS file *FD*, *FC*, and/or *WP* records.

Example 4 includes one *WR* record in the *SIM* input DAT file simply because *SIM* requires a minimum of at least one *WR* or *IF* record. Actual WRAP applications always include at least one water right and typically many water rights. However, the only purpose of Example 4 is to explore methods for the computation within *SIM* of naturalized flows at secondary control points given inputted naturalized flows at primary control points. The subsequent use by *SIM* of the naturalized flows in simulating water rights is not of interest in this example.

The parameters in each field of the *CP*, *FD*, *FC*, and *WP* records are explained in Chapter 3 of the *Users Manual*. The INMETHOD(cp) options selected in *CP* record field 6 are also defined in Table 3.2 of Chapter 3 of this *Reference Manual*. The reader's understanding of the flow distribution methods outlined in Chapter 3 can be confirmed or reinforced by manually replicating the *SIM* computational results presented here for Example 4.

The system consists of the five primary (known-flow) and four secondary (unknown-flow) control points shown in the schematic below. Naturalized flows at control points CP-I, CP-II, CP-III, and CP-IV are synthesized using INMETHOD(cp) option 7 for all four of the secondary control points.



System Schematic for Example 4

The only *SIM* input data employed in Example 4 are the DAT and DIS files reproduced on the following page. *SIM* was executed with these DAT and DIS input files. The naturalized flows were read from the *SIM* simulation results OUT file with *TABLES* using a 2NAT record and written by *TABLES* to its output TOU file as time series tables. The naturalized flows tabulated on the following page were copied from the time series table.

SIM Input DAT File for Example 4

```

**          1          2          3          4          5          6          7
**3456789012345678901234567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !      !      !      !      !      !      !      !
JD      1      2017          1      -1
JO      3
**
CP CP-J      CP-I                      NONE
CP CP-K      CP-I                      NONE
CP CP-L      CP-II                     NONE
CP CP-M      CP-II                     NONE
CP CP-N      CP-IV                     NONE          0.40
CP CP-I      CP-II                      7          NONE
CP CP-II     CP-N                      7          NONE          0.25
CPCP-III     OUT                      7          NONE
CP CP-IV     OUT                      7          NONE
**
WR CP-M
ED
IN CP-J 2017 4000 400 40 0 80 500 1000 2000 3000 4000 5000 6000
IN CP-K 2017 5000 500 50 0 90 1000 5200 5200 5200 5200 5200 5200
IN CP-L 2017 6500 650 500 0 500 500 7500 7500 7500 7500 7500 7500
IN CP-M 2017 6000 600 60 0 100 900 8000 8000 8000 8000 8000 8000
IN CP-N 2017 50000 5000 500 0 500 100 100000 0 0 100 8000 50000

```

SIM Input DIS File for Example 4

```

** Flow distribution FD records
**
FD CP-I      CP-N          2      CP-J      CP-K      CP-L      CP-M
FD CP-II     CP-N          4      CP-J      CP-K      CP-L      CP-M
FD CP-III    CP-N          0      CP-J      CP-K      CP-L      CP-M
FD CP-IV     CP-N          -1
**
** Watershed parameter WP records
**
WP CP-J      60.
WP CP-K      75.
WP CP-L      100.
WP CP-M      90.
WP CP-N      600.
WP CP-I      225.
WP CP-II     500.
WPCP-III    140.
WP CP-IV     800.
ED

```

Naturalized flows are provided as input on *IN* records for primary control points CP-J, CP-K, CP-L, CP-M, and CP-N. Default INMETHOD(cp) option 1 is indicated for these control points by the blank *CP* record field 6. INMETHOD(cp) option 7 is selected for each of the four secondary control points CP-I, CP-II, CP-III, and CP-IV. Option 7 is based on applying a drainage area ratio (Table 3.2, Equation 3.9) computed for either incremental subwatersheds or total watershed areas as explained in Chapter 3 of this manual. The following discussion illustrates the methodology outlined in Chapter 3 for defining subwatersheds.

**Naturalized Monthly Flow Volumes in acre-feet for
the 12 months of the Example 4 SIM Simulation**

CP	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CP-J	4,000	400	40	0	80	500	1,000	2,000	3,000	4,000	5,000	6,000
CP-K	5,000	500	50	0	90	1,000	5,200	5,200	5,200	5,200	5,200	5,200
CP-L	6,500	650	500	0	500	500	7,500	7,500	7,500	7,500	7,500	7,500
CP-M	6,000	600	60	0	100	900	8,000	8,000	8,000	8,000	8,000	8,000
CP-N	50,000	5,000	500	0	500	100	100,000	0	0	100	8,000	50,000
CP-I	20,086	2,009	94	0	170	1,500	33,601	7,200	8,200	9,200	10,200	21,010
CP-II	43,057	4,306	658	0	770	2,900	74,980	22,700	23,700	24,700	25,700	45,775
CP-III	17,245	1,725	6	0	0	0	42,624	0	0	0	0	15,260
CP-IV	46,667	4,667	467	0	467	93	93,333	0	0	93	7,467	46,667

Watersheds and subwatersheds are defined by the control point identifiers ID, DSG, and UGID(cp) specified on the flow distribution *FD* records. The parameter DA on the watershed parameter *WP* record is the drainage area in square miles. The parameter INWS(cp) in *CP* record field 12 specifies whether the drainage area DA on the *WP* record is for incremental subwatersheds or total watersheds. The default for INWS(cp) is total watershed areas.

For each secondary control point, there is one primary control point from which flows are transferred, which is called the source control point. Other primary control points located upstream may be used to define the local incremental watersheds for both the source control point and the ungaged (unknown-flow) secondary control point. The following information is provided on the *FD* record of the secondary control point for which flows are being computed.

- Control point identifier of secondary (unknown-flow) control point to which flows are being distributed entered as parameter ID in *FD* record field 2.
- Control point identifier of primary (known-flow) control point from which flows are being distributed entered as parameter DSG in *FD* record field 3.
- Control point identifiers of the upstream control points used to compute incremental flows entered as any number of UGID(cp) identifiers on the *FD* record.
- The number of upstream control points used to compute the incremental flows at the secondary control point entered as NG in *FD* record field 4. The first NG of the UGID(cp) listed on the *FD* record delineate the secondary CP subwatershed.

INMETHOD(cp) option 7 adopted in this example is based on applying a drainage area ratio R_{DA} (Eq. 3.9) to determine the flow from the defined local incremental subwatershed.

$$Q_{\text{unknown}} = Q_{\text{known}} R_{DA}$$

However, as discussed later, the same methodology employed here for delineating incremental subwatersheds is applied with alternative INMETHOD(cp) options 3, 4, 5, 6, 7, and 8.

Referring to the *FD* record for control point CP-I, the two drainage areas used in determining R_{DA} are (1) the area between downstream CP-I and upstream CP-J and CP-K and (2) the area between downstream CP-N and upstream CP-J, CP-K, CP-L, and CP-M. The flow computed each month using Equation 3.9 is added to the flows at control points CP-J and CP-K.

The naturalized flow volumes Q(I), Q(II), Q(III), and Q(IV) for the month of January 2017 at the secondary control points CP-I, CP-II, CP-III, and CP-IV are manually computed below to illustrate the methodology outlined in Chapter 3. Variables are defined on page 55. Watershed areas from the *WP* records, channel loss factors from the *CP* records, January 2017 naturalized flows from the *IN* records for the five primary control points, and the computed naturalized flows for the four secondary control points are tabulated in the table below.

Control Point	Watershed Area from <i>WP</i> record (square miles)	Loss Factor from <i>CP</i> record	January 2017 Flow Volume (acre-feet)
CP-J	60	-	4,000
CP-K	75	-	5,000
CP-L	100	-	6,500
CP-M	90	-	6,000
CP-N	600	0.40	50,000
CP-I	225	-	20,086
CP-II	500	0.25	43,057
CP-III	140	-	17,245
CP-IV	800	-	46,667

The incremental subwatershed drainage area and flow at the source control point CP-N are computed as follows.

$$\text{DAGAGE(N)} = \text{DA(N)} - \text{DA(J)} - \text{DA(K)} - \text{DA(L)} - \text{DA(M)}$$

$$\text{DAGAGE(N)} = 600 - 60 - 75 - 100 - 90 = 275 \text{ square miles}$$

$$\text{QGAGE(N)} = \text{Q(N)} - (1.0 - F_{CL}) [\text{Q(J)} + \text{Q(K)} + \text{Q(L)} + \text{Q(M)}]$$

$$\text{QGAGE(N)} = 50,000 - (1.0 - 0.25) (4,000 + 5,000 + 6,500 + 6,000) = 33,875 \text{ ac-ft}$$

The naturalized monthly flow volume Q(I) for control point CP-I is computed as follows.

$$\text{DAUG(I)} = \text{DA(I)} - \text{DA(J)} - \text{DA(K)} = 225 - 60 - 75 = 90 \text{ square miles}$$

$$\text{QUG(I)} = R_{DA} \text{ QGAGE(N)} = (90 \text{ mile}^2 / 275 \text{ mile}^2) (33,875 \text{ ac-ft}) = 11,086 \text{ acre-feet}$$

$$\text{Q(I)} = \text{QUG(I)} + \text{Q(J)} + \text{Q(K)} = 11,086 + 4,000 + 5,000 = 20,086 \text{ acre-feet}$$

The naturalized monthly flow volume Q(II) for control point CP-II is computed as follows.

$$\text{DAUG(II)} = \text{DA(II)} - \text{DA(J)} - \text{DA(K)} - \text{DA(L)} - \text{DA(M)}$$

$$\text{DAUG(II)} = 500 - 60 - 75 - 100 - 90 = 175 \text{ square miles}$$

$$\text{QUG(II)} = R_{DA} \text{ QGAGE(N)} = (175 \text{ mile}^2 / 275 \text{ mile}^2) (33,875 \text{ ac-ft}) = 21,557 \text{ acre-feet}$$

$$\text{Q(II)} = \text{QUG(II)} + \text{Q(J)} + \text{Q(K)} + \text{DA(L)} + \text{DA(M)}$$

$$\text{Q(II)} = 21,557 + 4,000 + 5,000 + 6,500 + 6,000 = 43,057 \text{ acre-feet}$$

The naturalized monthly flow volume Q(III) for control point CP-III is computed as follows.

$$\text{DAUG(III)} = 140 \text{ square miles}$$

$$\text{Q(III)} = \text{QUG(III)} = \text{R}_{\text{DA}} \text{QGAGE(N)} = (140/275)(33,875) = 17,245 \text{ acre-feet}$$

The naturalized monthly flow volume Q(IV) for control point CP-IV is computed as follows.

$$\text{DAUG(IV)} = \text{DA(IV)} - \text{DA(J)} = 800 - 600 = 200 \text{ square miles}$$

$$\text{QUG(IV)} = \text{R}_{\text{DA}} \text{QGAGE(N)} = (200/600)(50,000) = 16,667 \text{ acre-feet}$$

$$\text{Q(IV)} = \text{QUG(IV)} + (1.0 - \text{F}_{\text{CL}})(\text{Q(N)}) = 16,667 + (0.6)(50,000) = 46,667 \text{ acre-feet}$$

The flow distribution computations for each secondary control point are defined by the INMETHOD(cp) option selected in CP record field 6 and the FD record entries for ID, DSG, NG, and [UGID(I),I=1,MAXGAG]. A variety of different alternative subwatershed delineations could be adopted for Example 4. Likewise, different INMETHOD(cp) options could be selected. Different INMETHOD(cp) options can be applied using the same subwatershed delineations.

The CP record field 6 INMETHOD(cp) options for providing sequences of naturalized stream flow volumes for a control point in a SIM simulation are listed as follows.

- 1 Naturalized flows at the control point are provided as input data on IN records.
- 2 Flows from another control point are repeated without change except for a multiplier.
- 3 Equation 3.10 is used to compute flows: $Q_{\text{ungaged}} = a (Q_{\text{gaged}})^b + c$
- 4 NRCS CN method adaptation with maximum limit on computed flow.
- 5 NRCS CN method adaptation without maximum limit on computed flow.
- 6 Eq. 3.11 incorporating a channel loss coefficient into the drainage area ratio method.
- 7 Simple ratio of drainage areas from WP records is used. $Q_{\text{ungaged}} = Q_{\text{gaged}} \text{R}_{\text{DA}}$
- 8 An iterative algorithm incorporates channel losses in the NRCS CN method.
- 9 Flows are not provided for this control point.
- 10 Flows are computed in proportion to flows at other control points with Eq. 3.23.

Option 1 is employed for control points CP-J, CP-K, CP-L, CP-M, and CP-N in Example 4. Option 7 was used to incremental subwatershed flows QUG(I), QUG(II), QUG(III), and QUG(IV) for control points CP-I, CP-II, CP-III, and CP-IV in Example 4.

INMETHOD(cp) option 2 allows flows to be computed from flows at another control point using a drainage area ratio or other multiplier factor entered on the CP record without needing a FD or WP record. However, only total watershed areas, not incremental, can be used.

Option 3 can be adopted for computing QUG(cp) for any or all of the Example 4 secondary control points by changing the INMETHOD(cp) entry from 7 to 3 and adding FC records with values for the coefficients a, b, and c of Equation 3.10. With the appropriate R_{DA} entered for coefficient "a", and 1.0, and 0.0 entered for "b" and "c", the results are identical to the results with option 7. However, option 3 allows a non-linear regression relationship to be used.

Option 7	$Q_{\text{ungaged}} = \text{R}_{\text{DA}} Q_{\text{gaged}}$	Equation 3.9
----------	--	--------------

Option 3	$Q_{\text{ungaged}} = a Q_{\text{gaged}}^b + c$	Equation 3.10
----------	---	---------------

INMETHOD(cp) option 4 is based on Equations 3.16 and 3.17, with values for the curve number (CN) and mean precipitation (MP) for all relevant control points provided as parameters CN and MP on the *WP* records in the DIS file. Option 4 can be adopted for any or all of the Example 4 secondary control points by changing the INMETHOD(cp) entry from 7 to 4 on the *CP* record and adding values for CN and MP on the *WP* records. If the same value for CN and the same value for MP are entered for all relevant primary and secondary control points, option 4 yields identically the same results as option 7. However, the purpose of option 4 is to capture differences in the runoff and rainfall characteristics of the gaged and ungaged watersheds. Control point CP-I is used to illustrate the computations. With the same CN of 80 and MP of 30 inches (or any other same CN and MP) for the incremental watersheds of both CP-N and CP-I, the option 4 computations yield the same results as the previous option 7 computations.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} = \frac{(P - 0.2(2.5))^2}{P + 0.8(2.5)}$$

$$\left[\frac{33,874 \text{ acre-feet}}{(275 \text{ square miles})(640 \text{ af/sm})} \right] \left[\frac{12 \text{ inches}}{\text{foot}} \right] = \frac{(P - 0.2(2.5 \text{ inches}))^2}{P + 0.8(2.5 \text{ inches})}$$

$$P = 4.321 \text{ inches} \quad \text{Adjusted } P = (4.321 \text{ inches})(30 \text{ inches}/30 \text{ inches}) = 4.321 \text{ inches}$$

$$\left[\frac{\text{QUG(I)}}{(90 \text{ square miles})(640 \text{ af/sm})} \right] \left[\frac{12 \text{ inches}}{\text{foot}} \right] = \frac{(4.321 \text{ inches} - 0.2(2.5 \text{ inches}))^2}{4.321 \text{ inches} + 0.8(2.5 \text{ inches})}$$

$$\text{QUG(I)} = 11,086 \text{ acre-feet}$$

$$Q(I) = \text{QUG(I)} + Q(J) + Q(K) = 11,086 + 4,000 + 5,000 = 20,086 \text{ acre-feet}$$

With option 4, if the computed QUG(cp) exceeds QGAGE(cp), it is set equal to QGAGE(cp). Option 5 identical to option 4 except QUG(cp) is allowed to exceed QGAGE(cp).

Options 6 and 8 are variations of options 7 and 4. Options 6 and 8 are valid for CP-I and CP-II, but are not applicable for CP-III and CP-IV in Example 4. As explained in Chapter 3, due to methods employed for dealing with channel losses between the source and secondary control points, the secondary control point must be located upstream of the source control point.

Options 3-8 are alternative methods for computing incremental subwatershed flows QUG(cp). Option 10 is a different approach that generates flows as a function of total flows multiple source control points, with no explicit delineation of subwatersheds. With option 10, total flows Q(cp) are computed without computing QUG(cp). Option 10 allows any number of source control points. The CP-II flows can be computed with option 10 using the following input records, where the coefficient 1.539 is the drainage area ratio $R_{DA} = 500/(60+75+100+90) = 1.539$. The manual computations for January are shown below to illustrate the methodology.

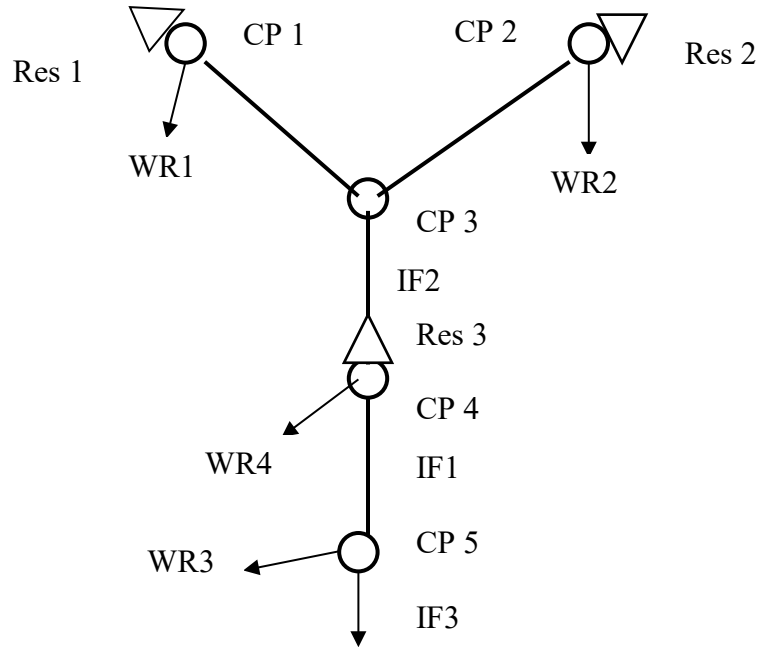
CP	CP-II	CP-N		10		NONE	0.25
FD	CP-II		4	CP-J	CP-K	CP-L	CP-M
FC	1.539	1.0	0.0	1.0	1.0	1.0	1.0

$$Q_{\text{ungaged}} = C_1 [C_4 Q_1 + C_5 Q_2 + C_6 Q_3 + \dots C_{N+3} Q_N]^{C_2} + C_3 \quad (3.23)$$

$$Q(\text{II}) = 1.539 (4,000 + 5,000 + 6,500 + 6,000) = 33,088 \text{ acre-feet}$$

Example 5 Featuring Target Options *TO* and Target Series *TS* Records

The purpose of Example 5 is to illustrate the use of target options *TO* and target series *TS* records in specifying instream flow and diversion targets. The *TABLES* output file is developed in a columnar format that facilitates transporting the simulation results to a spreadsheet program for plotting or other data manipulations. A schematic of the system is provided below and each water right is described.



System Schematic for Example 5

Instream Flow Right IF 1. The instream flow target at control point CP4 is set equal to the incremental naturalized flows entering the river above CP4 and below CP1 and CP2 constrained by lower and upper bounds. *TO* records are used to subtract (*NFACT*= -1) the naturalized (*TOFLOW*=1) flows at CP1 and CP2 from those at CP4. Instream flow right *IF1* has another feature that limits the target to the range from 3 to 68 ac-ft/month (*TO* record fields 7 and 8). If the incremental (CP4 - CP1 - CP2) flow is below 3 ac-ft, the target is set at 3 ac-ft. Likewise, if the CP4-CP1-CP2 naturalized flow is above 68 ac-ft, the target is set at 68 ac-ft.

Instream Flow Right IF 2. An instream flow requirement at CP3 varies between the two years of the simulation period-of-analysis. A *TS* record is entered for each year.

Instream Flow Right IF 3. The instream flow target at CP5 consists of the flow values entered on the *TS* record added to the minimum of: (a) 100 ac-ft/month or (b) the naturalized stream flow at CP5.

Water Rights WR 1, WR 2, and WR 4. These are standard type 1 rights with both a diversion and reservoir storage.

Water Right WR 3. WR3 is a run-of-river diversion right at control point CP5. The monthly diversion target is the lesser of 400 ac-ft or the naturalized stream flow at CP5.

Water Rights WR 5 and WR 7. WR5 diverts water from reservoir Res 3 at CP4 and transports it to CP1 for refilling by WR7 of storage in Res 1. The WR5 diversion target is computed as the minimum of the drawdown in Res 1 and the regulated flow at CP1. This models a situation in which Res 1 and Res 3 are operated as a system with the operating rules being based on maintaining as much storage in Res 1 as possible even though Res 3 has the more senior water right permit. There is actually no pipeline/pumping facility. Flows are allocated in accordance with the water rights priority system except WR5 and WR7 are added at the end of the priority loop to reallocate releases from Res 1 back to Res 1 from Res 3. Thus, the WR5 dummy diversion is limited to the regulated flows below Res 1 (representing downstream releases) and the storage drawdown in Res 1. WR7 uses the water diverted to CP1 to refill Res 1.

Water Rights WR 6 and WR 8. WR6 diverts water from reservoir Res 3 at CP4 and transports it to CP2 for refilling by WR8 of storage in Res 2. This models a situation in which Res 2 and Res 3 are operated as a system with the operating rules being based on maintaining as much storage in Res 2 as possible even though Res 3 has the more senior water right permit. There is a pipeline/pumping facility so flows are not limited to the regulated flows below Res 2 as done for WR 5 above.

TABLES Input File for Example 5

```

COMM TABLES Input File Exam5.TIN
COMM Example 5
2NAT 0 1 1 0 0
2REG 0 1 0 0 0
2STO 0 1 1 2 3
IDEN Res 1 Res 2 Res 3
2DIV 0 1 1 1 3
IDEN WR3 WR5 WR6
2SHT 0 1 0 1 -3
ENDF

```

WRAP-SIM FLO File for Example 5

```

** WRAP-SIM Input File Exam5.FLO
** Example 5 from Appendix C of Reference Manual
**
** Naturalized Streamflow
**
IN CP1 2006 60 60 60 120 120 120 10 10 10 10 10 10
IN CP2 2006 20 20 20 90 90 90 0 0 0 0 0 0
IN CP3 2006 120 120 120 240 240 240 30 30 30 30 30 30
IN CP4 2006 120 120 120 460 460 460 40 40 40 40 40 40
IN CP5 2006 150 150 150 680 680 680 50 50 50 50 50 50
IN CP1 2007 60 60 60 300 300 300 10 10 10 10 10 10
IN CP2 2007 20 20 20 100 100 100 0 0 0 0 0 0
IN CP3 2007 120 120 120 500 500 500 30 30 30 30 30 30
IN CP4 2007 120 120 120 600 600 600 40 40 40 40 40 40
IN CP5 2007 150 150 150 900 900 900 50 50 50 50 50 50

```

WRAP-SIM DAT File for Example 5

```

T1 WRAP-SIM Input File Exam5.DAT
T2 Example 5 from Appendix C of Reference Manual
**
JD      2      2006      1      -1      -1
JO      -1
RO      3      Res 1      Res 2      Res 3
**
CP      CP1      CP3                        NONE
CP      CP2      CP3                        NONE
CP      CP3      CP4                        NONE
CP      CP4      CP5                        NONE
CP      CP5      OUT                       NONE
**      ! 1      ! 2      ! 3      ! 4      ! 5      ! 6      ! 7      ! 8      ! 9      ! 10      ! 11 !
**345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !      !      !      !      !      !
**
** Water Right IF1 -----
IF      CP4                        1900      2                        IF1
TO      1                        CP4
TS      1      - 1.0      ADD                        CP1
TO      1      - 1.0      ADD      3.0      68.0      CP2
** Water Right IF2 -----
IF      CP3                        1901      2                        IF2
TS      2006      20.      20.      20.      20.      20.      20.      20.      20.      20.      20.      20.
TS      2007      15.      15.      15.      15.      15.      15.      15.      15.      15.      15.      15.
** Water Right IF3 -----
IF      CP5      1200.      1902      2                        IF3
TO      1                        MIN                        CP5
TS      ADD20062007      25.      25.      25.      30.      30.      0.      0.      0.      40.      40.      40.
** Water Right WR1 -----
WR      CP1      2400.      1985                        WR1
WS      Res 1      5000.      .1      1.
** Water Right WR2 -----
WR      CP2      2400.      1978                        WR2
WS      Res 2      5000.      .1      1.
** Water Right WR3 -----
WR      CP5      4800.      1903                        WR3
TO      1                        MIN                        CP5
** Water Right WR4 -----
WR      CP4      3600.      1950                        WR4
WS      Res 3      8000.      .1      1.
** Water Right WR5 -----
WR      CP4      0.      2000      3      1.0      CP1      WR5
WS      Res 3      8000.      .1      1.
TO      5                        Res 1
TO      2                        MIN                        CP1
** Water Right WR6 -----
WR      CP4      0.      2000      3      1.0      CP2      WR6
WS      Res 3      8000.      .1      1.
TO      5                        Res 2
** Water Right WR7 -----
WR      CP1      0.      2001                        WR7
WS      Res 1      5000.      .1      1.
** Water Right WR8 -----
WR      CP2      0.      2001                        WR8
WS      Res 2      5000.      .1      1.
** -----
**
**      !      !      !      !      !      !      !      !      !      !      !      !      !
**345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
**      ! 1      ! 2      ! 3      ! 4      ! 5      ! 6      ! 7      ! 8      ! 9      ! 10      ! 11 !
**
ED

```

TABLES Output File for Example 5

		2NAT CP1	2NAT CP2	2NAT CP3	2NAT CP4	2NAT CP5	2REG CP1	2REG CP2	2REG CP3	2REG CP4	2REG CP5
2006	1	60.00	20.00	120.00	120.00	150.00	0.00	80.00	120.00	120.00	125.00
2006	2	60.00	20.00	120.00	120.00	150.00	0.00	80.00	120.00	120.00	125.00
2006	3	60.00	20.00	120.00	120.00	150.00	0.00	80.00	120.00	120.00	125.00
2006	4	120.00	90.00	240.00	460.00	680.00	0.00	210.00	240.00	310.00	130.00
2006	5	120.00	90.00	240.00	460.00	680.00	0.00	210.00	240.00	310.00	130.00
2006	6	120.00	90.00	240.00	460.00	680.00	0.00	210.00	240.00	310.00	130.00
2006	7	10.00	0.00	30.00	40.00	50.00	0.00	10.00	30.00	40.00	50.00
2006	8	10.00	0.00	30.00	40.00	50.00	0.00	10.00	30.00	40.00	50.00
2006	9	10.00	0.00	30.00	40.00	50.00	0.00	10.00	30.00	40.00	50.00
2006	10	10.00	0.00	30.00	40.00	50.00	0.00	50.00	70.00	80.00	90.00
2006	11	10.00	0.00	30.00	40.00	50.00	0.00	50.00	70.00	80.00	90.00
2006	12	10.00	0.00	30.00	40.00	50.00	0.00	50.00	70.00	80.00	90.00
2007	1	60.00	20.00	120.00	120.00	150.00	0.00	80.00	120.00	120.00	125.00
2007	2	60.00	20.00	120.00	120.00	150.00	0.00	80.00	120.00	120.00	125.00
2007	3	60.00	20.00	120.00	120.00	150.00	60.00	20.00	120.00	120.00	125.00
2007	4	300.00	100.00	500.00	600.00	900.00	300.00	100.00	500.00	230.00	130.00
2007	5	300.00	100.00	500.00	600.00	900.00	300.00	100.00	500.00	230.00	130.00
2007	6	300.00	100.00	500.00	600.00	900.00	300.00	100.00	500.00	230.00	130.00
2007	7	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00
2007	8	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00
2007	9	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00
2007	10	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00
2007	11	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00
2007	12	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00

		2STO Res 1	2STO Res 2	2STO Res 3	2DIV WR3	2DIV WR5	2DIV WR6	2SHT WR3	2SHT WR5	2SHT WR6
2006	1	4920.00	4940.00	7440.00	25.00	60.00	200.00	125.00	0.00	0.00
2006	2	4840.00	4940.00	6820.00	25.00	60.00	260.00	125.00	0.00	0.00
2006	3	4760.00	4940.00	6200.00	25.00	60.00	260.00	125.00	0.00	0.00
2006	4	4800.00	4880.00	5670.00	400.00	120.00	260.00	0.00	0.00	0.00
2006	5	4840.00	4880.00	5080.00	400.00	120.00	320.00	0.00	0.00	0.00
2006	6	4880.00	4880.00	4490.00	400.00	120.00	320.00	0.00	0.00	0.00
2006	7	4700.00	4990.00	3860.00	0.00	10.00	320.00	50.00	0.00	0.00
2006	8	4520.00	4990.00	3340.00	0.00	10.00	210.00	50.00	0.00	0.00
2006	9	4340.00	4990.00	2820.00	0.00	10.00	210.00	50.00	0.00	0.00
2006	10	4160.00	4950.00	2300.00	0.00	10.00	210.00	50.00	0.00	0.00
2006	11	3980.00	4950.00	1740.00	0.00	10.00	250.00	50.00	0.00	0.00
2006	12	3800.00	4950.00	1180.00	0.00	10.00	250.00	50.00	0.00	0.00
2007	1	3720.00	4940.00	570.00	25.00	60.00	250.00	125.00	0.00	0.00
2007	2	3640.00	4890.00	0.00	25.00	60.00	210.00	125.00	0.00	50.00
2007	3	3440.00	4690.00	0.00	25.00	0.00	0.00	125.00	60.00	310.00
2007	4	3310.00	4490.00	0.00	400.00	70.00	0.00	0.00	230.00	510.00
2007	5	3180.00	4290.00	0.00	400.00	70.00	0.00	0.00	230.00	710.00
2007	6	3050.00	4090.00	0.00	400.00	70.00	0.00	0.00	230.00	910.00
2007	7	2850.00	3890.00	0.00	0.00	0.00	0.00	50.00	10.00	1110.00
2007	8	2650.00	3690.00	0.00	0.00	0.00	0.00	50.00	10.00	1310.00
2007	9	2450.00	3490.00	0.00	0.00	0.00	0.00	50.00	10.00	1510.00
2007	10	2250.00	3290.00	0.00	0.00	0.00	0.00	50.00	10.00	1710.00
2007	11	2050.00	3090.00	0.00	0.00	0.00	0.00	50.00	10.00	1910.00
2007	12	1850.00	2890.00	0.00	0.00	0.00	0.00	50.00	10.00	2110.00

Example 6 Modeling a Multiple-Owner Reservoir

The purpose of Example 6 is to illustrate the use of evaporation allocation *EA*, evaporation allocation factors *EF*, and stream flow availability allocation factors *AF* records to model a reservoir owned by multiple entities. Models are formulated with and without use of *EA*, *EF*, and *AF* records for comparison.

Three water supply entities share the conservation pool of a federal reservoir project. Entities 1 and 2 have each contracted for 40 percent of the conservation storage capacity. Entity 3 has contracted for the remaining 20 percent of the storage capacity. Water supply contracts were executed at project construction and the water right permits have the same priority date. If the three entities each withdraw water from the reservoir in proportion to their storage capacity, the allocation is simple as illustrated by the following *SIM* input and *TABLES* output files.

```
T1 WRAP-SIM Input File Exam6B.DAT
T2 Example 6 from Appendix C of Reference Manual
T3 Single Reservoir for Comparison
JD 2 2015 1 -1 -1
JO 3
CP CP1
WR CP1 300000 1 WR-1B
WS Res-A 500000
SV Res-A 0 100000 200000 400000 500000
SA 0 10000 20000 40000 50000
ED
IN CP1 2015 100000 100000 100000 0 0 0 0 0 0 10000 10000 10000
EV CP1 2015 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
IN CP1 2016 20000 20000 20000 500000 500000 500000 0 0 0 10000 20000 50000
EV CP1 2016 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
```

MONTHLY SUMMARY TABLE FOR WATER RIGHT WR-1B

YEAR	MONTH	AVAILABLE STREAMFLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	SYSTEM RELEASES (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	SHORTAGE (AC-FT)
2015	1	100000.0	35000.0	500000.0	10000.0	0.0	25000.0	25000.0	0.0
2015	2	100000.0	35000.0	500000.0	10000.0	0.0	25000.0	25000.0	0.0
2015	3	100000.0	35000.0	500000.0	10000.0	0.0	25000.0	25000.0	0.0
2015	4	0.0	0.0	465346.5	9653.5	0.0	25000.0	25000.0	0.0
2015	5	0.0	0.0	431379.3	8967.3	0.0	25000.0	25000.0	0.0
2015	6	0.0	0.0	398084.6	8294.6	0.0	25000.0	25000.0	0.0
2015	7	0.0	0.0	365449.3	7635.3	0.0	25000.0	25000.0	0.0
2015	8	0.0	0.0	333460.2	6989.1	0.0	25000.0	25000.0	0.0
2015	9	0.0	0.0	302104.5	6355.6	0.0	25000.0	25000.0	0.0
2015	10	10000.0	10000.0	281270.8	5833.8	0.0	25000.0	25000.0	0.0
2015	11	10000.0	10000.0	260849.6	5421.2	0.0	25000.0	25000.0	0.0
2015	12	10000.0	10000.0	240832.8	5016.8	0.0	25000.0	25000.0	0.0
2016	1	20000.0	20000.0	224206.8	11626.0	0.0	25000.0	25000.0	0.0
2016	2	20000.0	20000.0	208391.8	10815.0	0.0	25000.0	25000.0	0.0
2016	3	20000.0	20000.0	193348.3	10043.5	0.0	25000.0	25000.0	0.0
2016	4	500000.0	348985.4	500000.0	17333.7	0.0	25000.0	25000.0	0.0
2016	5	500000.0	50000.0	500000.0	25000.0	0.0	25000.0	25000.0	0.0
2016	6	500000.0	50000.0	500000.0	25000.0	0.0	25000.0	25000.0	0.0
2016	7	0.0	0.0	451219.5	23780.5	0.0	25000.0	25000.0	0.0
2016	8	0.0	0.0	404818.5	21400.9	0.0	25000.0	25000.0	0.0
2016	9	0.0	0.0	360681.0	19137.5	0.0	25000.0	25000.0	0.0
2016	10	10000.0	10000.0	328452.7	17228.3	0.0	25000.0	25000.0	0.0
2016	11	20000.0	20000.0	307552.6	15900.1	0.0	25000.0	25000.0	0.0
2016	12	50000.0	50000.0	316940.2	15612.3	0.0	25000.0	25000.0	0.0
MEAN		82083.3	30166.1	369766.2	12793.5	0.0	25000.0	25000.0	0.0

In the model on the preceding page, the three entities sharing the reservoir are simply treated as the one water right WR-1B. If the 25,000 acre-feet/month diversion target is divided between them in proportion to their storage capacity, their allocations are 10,000 ac-ft/month, 10,000 ac-ft/month, and 5,000 ac-ft/month. Diversions and shortages are allocated in the same proportion. However, adoption of a modeling strategy based on three component reservoirs and *EA*, *EF*, and *AF* records would be motivated by the complexity of the three entities having different diversion needs. If an entity diverts little water relative to its ownership of storage capacity, it should have more water in storage to provide protection against future drought conditions. An accounting system is needed to keep track of the amount of water that each of the three water supply entities has in storage.

The following model formulation illustrates the component reservoir strategy described in Chapter 4 for accounting for water in a reservoir shared by multiple owners. The storage and diversions allocated to each of the three entities are tracked by assigning each a "*computational*" component reservoir representing its share of the actual single reservoir. The *EA* and *EF* records are used to allocate the actual total net evaporation-precipitation between the three component reservoirs. The approach presented on the preceding page would actually be adopted for the simple case in which water supply diversions occur in the same proportion as storage capacity, and the three entities share the same water right priority. However, this simple example provides an opportunity to explore simulation features by comparing results for the model presented on the preceding page with the results for the model on the next page.

The *AF* record would not be used if the three entities had different water right priorities. However, since they share the same priority, the *AF* record factors provide a scheme to allocate available stream flow to the three rights in the priority-based simulation sequence. The available stream flow is allocated in proportion to storage capacity. WR-1, which is considered first in the water right computational loop priority sequence, is restricted to appropriate no more than 40 percent of the available stream flow. WR-2 which is considered next in the priority sequence is restricted to no more than two-thirds of the remaining available stream flow. WR-3 is considered last in the computational sequence and has access to all of the remaining available stream flow.

Since there are no diversion shortages, the resulting control point summary table is identical for either the model presented below or the model presented on the presenting page. The stream flow depletion, diversion, storage, and evaporation volumes for WR-1, WR-2, and WR-3 in the model on the following pages sum to the values for WR-1B of the model on the preceding page.

The allocation of evaporation between WR-1, WR-2, and WR-3 is approximate and does not result in perfectly matching evaporation volumes in proportion to storage capacity for the following reason. Evaporation and end-of-month storage volumes are computed in an iterative algorithm since each depends upon the other. When the computations are performed for WR-1, the other two water rights have not yet been considered, and thus the final end-of-month storage is not yet known. Likewise, computations for WR-2 are performed prior to consideration of WR-3. The correct total evaporation volume is maintained because the evaporation allocated to WR-3 is computed as the correct total volume minus the amounts allocated to WR-1 and WR-2.

WRAP-SIM Input File for Example 6

```

T1 WRAP-SIM Input File Exam6.DAT
T2 Example 6 from Appendix C of Reference Manual
T3 Illustrating Evaporation and Available Flow Allocation EA, EF, and AF Records
**
** The allocation of storage capacity, net evaporation-precipitation, and available streamflow is illustrated
** with this simple data set. Res-A, Res-B, and Res-C are "computational" component reservoirs representing a
** single actual reservoir owned/shared by three water supply entities. The three component reservoirs have a
** common storage-area relationship which is provided as SV/SA records assigned to Res-A.
**
JD      2      2015      1      -1      -1
JO      3
**
CP      CP1
**      1          2          3          4          5          6          7
**3456789012345678901234567890123456789012345678901234567890123456789012
**      !          !          !          !          !          !          !          !
WR      CP1      120000          1          WR-1
WS      Res-A    200000          1
**
WR      CP1      120000          2          WR-2
WS      Res-B    200000          1          -1
**
WR      CP1      60000          3          WR-3
WS      Res-C    100000          1          -1
**
SV      Res-A      0 100000 200000 400000 500000
SA      0 10000 20000 40000 50000
**
** 40%, 40%, and 20% of both the net evaporation and available streamflow are
** allocated to component reservoirs Res-A, Res-B, and Res-C, respectively.
**
EA      1          3      Res-A      Res-B      Res-C
EF      0          0          0.4      0.4
AF      0          0          0.40.666667      1.0
**
ED
**
IN      CP1      2015 100000 100000 100000 0 0 0 0 0 10000 10000 10000
EV      CP1      2015 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2
**
IN      CP1      2016 20000 20000 20000 500000 500000 500000 0 0 0 10000 20000 50000
EV      CP1      2016 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5

```

TABLES Input File for Example 6

```

COMM  TABLES Input File Exam6.TIN
2SWR  1
2SCP  1
ENDF

```

TABLES Output File for Example 6

MONTHLY SUMMARY TABLE FOR WATER RIGHT WR-1

YEAR	MONTH	AVAILABLE STREAMFLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	SYSTEM RELEASES (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	SHORTAGE (AC-FT)
2015	1	40000.0	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2015	2	40000.0	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2015	3	40000.0	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2015	4	0.0	0.0	186055.8	3944.2	0.0	10000.0	10000.0	0.0
2015	5	0.0	0.0	172387.7	3668.1	0.0	10000.0	10000.0	0.0
2015	6	0.0	0.0	158990.2	3397.4	0.0	10000.0	10000.0	0.0
2015	7	0.0	0.0	145858.1	3132.1	0.0	10000.0	10000.0	0.0
2015	8	0.0	0.0	132986.0	2872.1	0.0	10000.0	10000.0	0.0
2015	9	0.0	0.0	120368.8	2617.2	0.0	10000.0	10000.0	0.0
2015	10	4000.0	4000.0	111985.5	2383.3	0.0	10000.0	10000.0	0.0
2015	11	4000.0	4000.0	103768.2	2217.3	0.0	10000.0	10000.0	0.0
2015	12	4000.0	4000.0	95713.6	2054.6	0.0	10000.0	10000.0	0.0
2016	1	8000.0	8000.0	88964.4	4749.2	0.0	10000.0	10000.0	0.0
2016	2	8000.0	8000.0	82544.5	4419.9	0.0	10000.0	10000.0	0.0
2016	3	8000.0	8000.0	76437.7	4106.8	0.0	10000.0	10000.0	0.0
2016	4	200000.0	140495.8	200000.0	6933.5	0.0	10000.0	10000.0	0.0
2016	5	200000.0	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
2016	6	200000.0	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
2016	7	0.0	0.0	180198.0	9802.0	0.0	10000.0	10000.0	0.0
2016	8	0.0	0.0	161362.0	8836.0	0.0	10000.0	10000.0	0.0
2016	9	0.0	0.0	143444.8	7917.2	0.0	10000.0	10000.0	0.0
2016	10	4000.0	4000.0	130362.0	7082.8	0.0	10000.0	10000.0	0.0
2016	11	8000.0	8000.0	121877.8	6484.2	0.0	10000.0	10000.0	0.0
2016	12	20000.0	20000.0	125688.6	6189.2	0.0	10000.0	10000.0	0.0
MEAN		32833.3	12104.0	147458.0	5200.3	0.0	10000.0	10000.0	0.0

MONTHLY SUMMARY TABLE FOR WATER RIGHT WR-2

YEAR	MONTH	AVAILABLE STREAMFLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	SYSTEM RELEASES (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	SHORTAGE (AC-FT)
2015	1	57333.4	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2015	2	57333.4	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2015	3	57333.4	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2015	4	0.0	0.0	186111.3	3888.7	0.0	10000.0	10000.0	0.0
2015	5	0.0	0.0	172497.7	3613.6	0.0	10000.0	10000.0	0.0
2015	6	0.0	0.0	159153.6	3344.1	0.0	10000.0	10000.0	0.0
2015	7	0.0	0.0	146073.8	3079.8	0.0	10000.0	10000.0	0.0
2015	8	0.0	0.0	133253.0	2820.8	0.0	10000.0	10000.0	0.0
2015	9	0.0	0.0	120686.0	2566.9	0.0	10000.0	10000.0	0.0
2015	10	4000.0	4000.0	112336.1	2349.9	0.0	10000.0	10000.0	0.0
2015	11	4000.0	4000.0	104151.6	2184.6	0.0	10000.0	10000.0	0.0
2015	12	4000.0	4000.0	96129.1	2022.5	0.0	10000.0	10000.0	0.0
2016	1	8000.0	8000.0	89446.7	4682.3	0.0	10000.0	10000.0	0.0
2016	2	8000.0	8000.0	83090.4	4356.4	0.0	10000.0	10000.0	0.0
2016	3	8000.0	8000.0	77044.1	4046.3	0.0	10000.0	10000.0	0.0
2016	4	239669.6	139889.4	200000.0	6933.5	0.0	10000.0	10000.0	0.0
2016	5	320000.2	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
2016	6	320000.2	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
2016	7	0.0	0.0	180394.1	9605.9	0.0	10000.0	10000.0	0.0
2016	8	0.0	0.0	161744.5	8649.5	0.0	10000.0	10000.0	0.0
2016	9	0.0	0.0	144004.8	7739.8	0.0	10000.0	10000.0	0.0
2016	10	4000.0	4000.0	131051.5	6953.3	0.0	10000.0	10000.0	0.0
2016	11	8000.0	8000.0	122651.3	6400.2	0.0	10000.0	10000.0	0.0
2016	12	20000.0	20000.0	126424.4	6226.9	0.0	10000.0	10000.0	0.0
MEAN		46652.9	12078.7	147760.1	5144.4	0.0	10000.0	10000.0	0.0

MONTHLY SUMMARY TABLE FOR WATER RIGHT WR-3

YEAR	MONTH	AVAILABLE STREAMFLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	SYSTEM RELEASES (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	SHORTAGE (AC-FT)
2015	1	72000.0	7000.0	100000.0	2000.0	0.0	5000.0	5000.0	0.0
2015	2	72000.0	7000.0	100000.0	2000.0	0.0	5000.0	5000.0	0.0
2015	3	72000.0	7000.0	100000.0	2000.0	0.0	5000.0	5000.0	0.0
2015	4	0.0	0.0	93179.4	1820.6	0.0	5000.0	5000.0	0.0
2015	5	0.0	0.0	86493.9	1685.5	0.0	5000.0	5000.0	0.0
2015	6	0.0	0.0	79940.8	1553.1	0.0	5000.0	5000.0	0.0
2015	7	0.0	0.0	73517.4	1423.4	0.0	5000.0	5000.0	0.0
2015	8	0.0	0.0	67221.3	1296.2	0.0	5000.0	5000.0	0.0
2015	9	0.0	0.0	61049.8	1171.5	0.0	5000.0	5000.0	0.0
2015	10	2000.0	2000.0	56949.2	1100.6	0.0	5000.0	5000.0	0.0
2015	11	2000.0	2000.0	52929.9	1019.3	0.0	5000.0	5000.0	0.0
2015	12	2000.0	2000.0	48990.1	939.8	0.0	5000.0	5000.0	0.0
2016	1	4000.0	4000.0	45795.6	2194.5	0.0	5000.0	5000.0	0.0
2016	2	4000.0	4000.0	42757.0	2038.7	0.0	5000.0	5000.0	0.0
2016	3	4000.0	4000.0	39866.5	1890.4	0.0	5000.0	5000.0	0.0
2016	4	219614.8	68600.2	100000.0	3466.7	0.0	5000.0	5000.0	0.0
2016	5	460000.0	10000.0	100000.0	5000.0	0.0	5000.0	5000.0	0.0
2016	6	460000.0	10000.0	100000.0	5000.0	0.0	5000.0	5000.0	0.0
2016	7	0.0	0.0	90627.4	4372.6	0.0	5000.0	5000.0	0.0
2016	8	0.0	0.0	81712.0	3915.4	0.0	5000.0	5000.0	0.0
2016	9	0.0	0.0	73231.5	3480.5	0.0	5000.0	5000.0	0.0
2016	10	2000.0	2000.0	67039.2	3192.3	0.0	5000.0	5000.0	0.0
2016	11	4000.0	4000.0	63023.5	3015.7	0.0	5000.0	5000.0	0.0
2016	12	10000.0	10000.0	64827.2	3196.3	0.0	5000.0	5000.0	0.0
MEAN		57900.6	5983.3	74548.0	2448.9	0.0	5000.0	5000.0	0.0

MONTHLY SUMMARY TABLE FOR CONTROL POINT CP1

YEAR	MONTH	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2015	1	100000.0	65000.0	65000.0	0.0	35000.0	500000.0	10000.0	25000.0	0.0
2015	2	100000.0	65000.0	65000.0	0.0	35000.0	500000.0	10000.0	25000.0	0.0
2015	3	100000.0	65000.0	65000.0	0.0	35000.0	500000.0	10000.0	25000.0	0.0
2015	4	0.0	0.0	0.0	0.0	0.0	465346.6	9653.5	25000.0	0.0
2015	5	0.0	0.0	0.0	0.0	0.0	431379.2	8967.3	25000.0	0.0
2015	6	0.0	0.0	0.0	0.0	0.0	398084.6	8294.6	25000.0	0.0
2015	7	0.0	0.0	0.0	0.0	0.0	365449.3	7635.3	25000.0	0.0
2015	8	0.0	0.0	0.0	0.0	0.0	333460.2	6989.1	25000.0	0.0
2015	9	0.0	0.0	0.0	0.0	0.0	302104.6	6355.6	25000.0	0.0
2015	10	10000.0	0.0	0.0	0.0	10000.0	281270.8	5833.8	25000.0	0.0
2015	11	10000.0	0.0	0.0	0.0	10000.0	260849.6	5421.2	25000.0	0.0
2015	12	10000.0	0.0	0.0	0.0	10000.0	240832.8	5016.8	25000.0	0.0
2016	1	20000.0	0.0	0.0	0.0	20000.0	224206.8	11626.0	25000.0	0.0
2016	2	20000.0	0.0	0.0	0.0	20000.0	208391.8	10815.0	25000.0	0.0
2016	3	20000.0	0.0	0.0	0.0	20000.0	193348.3	10043.5	25000.0	0.0
2016	4	500000.0	151014.6	151014.6	0.0	348985.4	500000.0	17333.7	25000.0	0.0
2016	5	500000.0	450000.0	450000.0	0.0	50000.0	500000.0	25000.0	25000.0	0.0
2016	6	500000.0	450000.0	450000.0	0.0	50000.0	500000.0	25000.0	25000.0	0.0
2016	7	0.0	0.0	0.0	0.0	0.0	451219.5	23780.5	25000.0	0.0
2016	8	0.0	0.0	0.0	0.0	0.0	404818.6	21400.9	25000.0	0.0
2016	9	0.0	0.0	0.0	0.0	0.0	360681.1	19137.5	25000.0	0.0
2016	10	10000.0	0.0	0.0	0.0	10000.0	328452.7	17228.3	25000.0	0.0
2016	11	20000.0	0.0	0.0	0.0	20000.0	307552.6	15900.1	25000.0	0.0
2016	12	50000.0	0.0	0.0	0.0	50000.0	316940.3	15612.3	25000.0	0.0
MEAN		82083.3	51917.3	51917.3	0.0	30166.1	369766.2	12793.5	25000.0	0.0

Example 7 Focusing on Multiple-Reservoir System Operations

The previous Example 6 includes multiple-reservoir system operations along with other features. Example 7 focuses specifically on modeling multiple reservoir system operations. Simple numbers are adopted for the example in order to make the computations easy to track in the simulation results. All four of the reservoirs in the example are identical for simplicity.

The four-reservoir system of Example 7 is configured as shown by the schematic of Figure 4.3 in Chapter 4. The example includes a type 2 diversion right located at control point CP-4 in Figure 4.3 that is supplied by releases from the four reservoirs and also a more senior priority type 1 run-of-river diversion right at control point CP-6. The four reservoirs are refilled by separate type 1 water rights.

Each of the four reservoirs is divided into two active pool zones as illustrated in Figure 4.1. Multiple reservoir release decisions are based on Equation 4.6 which is reproduced below.

$$\text{rank index} = M \left[\frac{\text{content}}{\text{capacity}} \right] + A \quad (4.6)$$

M and A for zones 1 and 2 are four factors entered on the *OR* record. The defaults are 1.0 for the multiplier factor M and 0.0 for the addition factor A.

By default, the storage content in Equation 4.6 is the storage volume of the reservoir at the beginning of the month. The parameter STOF LG in *JO* record field 11 activates an option in which beginning and ending storage content are averaged for Eq. 4.6 using the *latest* value of end-of-month storage volume. As the simulation is performed for each month, the end-of-month storage volume may change during the course of the computations. Since *JO* record field 11 is blank in this example, beginning-of-month storage content is used in Equation 4.6.

OR records are not required if defaults are adopted for all fields of the record. The defaults of 1.0 and 0.0 for M and A are adopted for each of the four reservoirs in Example 7. However, *OR* records are required for the example to input zone 2 storage and release capacity.

The reservoirs each have a conservation storage capacity of 10,000 acre-feet. For purposes of defining multiple-reservoir release rules, the active conservation pool of each of the reservoirs is divided into two zones (Figure 4.1) of 5,000 acre-feet each. With *WS* record field 7 blank, there is no inactive pool. Releases are constrained to not exceed the release capacity (maximum limit) of 3,000 acre-feet/month.

The *SIM* operating rules allow no reservoir to release from zone 2 unless zone 1 is empty in all four reservoirs. With storage contents extending into zone 1 in one or more reservoirs, the choice of reservoir from which to release from zone 1 in the current month is based on the rank index computed with Equation 4.6 for these reservoirs. The release is made from the reservoir with the highest value for the rank index. Likewise, with contents at or below the top of zone 2 (bottom of zone 1) in all reservoirs, the release is from the reservoir with the highest value for the rank index. The entire release for the month is made from the one selected reservoir unless constrained by the 3,000 acre-feet/month release limit or zone storage contents.

Since *OR* record field 6 is blank (SN2 = 0) for all four reservoirs, releases from the reservoirs are limited to supplying the diversion at control point CP-4 based on gravity flow. The parameter SN2 in *OR* field 6 also provides the alternative option of modeling conveyance through pipeline, canals, and pumping systems with no location constraints. Reservoirs Res-A, Res-B, and Res-C are located upstream of the diversion at control point C-4 and thus reservoir releases are transported by gravity flow from control points CP-1 (reservoir Res-A), CP-2 (reservoir Res-B), and CP-3 (reservoir Res-C) directly to the diversion at control point CP-4. However, reservoir Res-D at control point CP-5 is not located upstream of the diversion at CP-4. With SN2 of 0 in *OR* record field 6, reservoir Res-D is limited to gravity flow releases. Without the senior run-of-river diversion right at CP-6, reservoir Res-D could not participate in the multiple-reservoir system operations.

Although releases from storage are not required, inflows must be passed through reservoirs Res-A, Res-B, and Res-C to meet the requirements of the senior diversion right at control point CP-6. Releases from storage from reservoir Res-D can be made in lieu of passing inflows through reservoirs Res-A, Res-B, and Res-C. Without the SN2 conveyance option activated, this is the only way that reservoir Res-D can contribute to meeting the diversion target of the type 2 diversion right at control point CP-4. Thus, reservoir Res-D is a component of the four reservoir system from this perspective.

The rules defining operations of the four-reservoir system are specified with the *OR* records in the DAT file reproduced below based on equalizing storage draw-downs expressed as a percentage of storage capacity. The objective is to approximately equally balance the storage contents, as a percentage of storage capacity, between the four reservoirs. Each of the four pairs of *WR/OR* records contain the following entries.

WS	Res-A	10000.	0.1	1				
OR	CP-2	5000.	1.0	1.0	0	0.0	0.0	3000.

The zone 2 storage capacity in each reservoir could be changed from 5,000 acre-feet to zero by revising the *OR* records as follows. This means there is no zone 2.

OR	CP-2	0.	1.0	1.0	0	0.0	0.0	3000.
----	------	----	-----	-----	---	-----	-----	-------

With all four *OR* records the same, the multiple-reservoir release decision each month is still based on equally balancing the storage content of the four reservoirs, but the balancing is a little less precise. The non-zero storage capacity of 5,000 acre-feet provides opportunities be split the release between reservoirs in some months. Otherwise, the entire release for a month is from one reservoir, assuming that reservoir is not emptied and the release target does not reach the maximum limit of 3,000 acre-feet/month.

Alternatively, the reservoir operating rules can be based on purposely attempting to maintain storage contents, expressed as a percentage of storage capacity, higher in some reservoirs than in others. For example, the storage capacity of zone 2 of Res-A could be set at 10,000 acre-feet, eliminating zone 1, and at 5,000 acre-feet in the other three reservoirs. No releases would be made from Res-A, which has no zone 1, until zone 1 is emptied in the other three reservoirs. With a little ingenuity, various operating strategies can be modeled by adjusting the zones. The factors M and A in Equation 4.6 provide additional flexibility.

The multiple-reservoir operating rules defined by the *OR* record for determining the release in each month are summarized as follows.

- No release is made from zone 2 of any reservoir as long as water is contained in zone 1 of one or more other reservoirs.
- The release capacity, which is specified to be 3,000 acre-feet/month in this example, is a maximum limit that cannot be exceeded.
- The release in a given month is made from the reservoir with the highest value of the rank index of Equation 4.6. The entire release for the month is from the one selected reservoir unless either the bottom of the storage zone or the release capacity are reached. Two or more reservoirs may release in the same month and as dictated by these limits.

Other *WRAP-SIM* options for simulating reservoir system operations that are not included Example 7 include the following.

- The multiplier factor *M* and addition factor *A* of Equation 4.6 entered on the *OR* record may have values other than the defaults of 1.0 and 0.0. These factors provide additional flexibility for defining the rank index that controls multiple-reservoir release decisions.
- An inactive storage pool may be specified on the *WS* record. The inactive pool has the default of zero in this example. No releases are made from the inactive pool.
- The release capacity of 3,000 acre-feet/month in *OR* record field 9 is a constant in this example. A flow switch *FS* record identifier entered in *OR* record field 10 allows the release limit to vary in accordance with the *FS* record.
- The four default type 1 rights that refill storage in this example fill the reservoirs to a target level of 10,000 acre-feet. Specifying water right type 7 in *WR* record field 6 allows a variable storage target that is computed by *SIM* each month in accordance with the target setting records which include drought (storage) index *DI*, target options *TO*, supplemental options *SO*, flow switch *FS*, target series *TS*, and backup *BU* records.
- Seasonal rule curve operations can be modeled in lieu of the constant 10,000 acre-foot conservation storage capacity using monthly-varying storage *MS* records.
- Multiple owners of any of the reservoirs can be modeled using the features illustrated in the previous Example 8.

SIM Input DAT File for Example 7

```
T1 SIM DAT File for Example 7 Focused on Multiple-Reservoir System Operations
**
**          1          2          3          4          5          6          7          8
**34567890123456789012345678901234567890123456789012345678901234567890
**      !          !          !          !          !          !          !          !
JD      2      2016          1          -1          -1          !          !          !          !
JO      3
RO     -1
```

Continuation of SIM Input DAT File for Example 7

```

**
CP CP-1 CP-2 NONE
CP CP-2 CP-4 NONE
CP CP-3 CP-4 NONE
CP CP-4 CP-6 NONE
CP CP-5 CP-6 NONE
CP CP-6 OUT NONE
**
WR CP-4 48000 2 2 Diversion Right
WS Res-A 10000 0.1 1
OR CP-1 5000 1.0 1.0 0 0.0 0.0 3000.
WS Res-B 10000 0.1 1
OR CP-2 5000 1.0 1.0 0 0.0 0.0 3000.
WS Res-C 10000 0.1 1
OR CP-3 5000 1.0 1.0 0 0.0 0.0 3000.
WS Res-D 10000 0.1 1
OR CP-5 5000 1.0 1.0 0 0.0 0.0 3000.
**
WR CP-1 3 Refill Storage A
WS Res-A 10000
WR CP-2 3 Refill Storage B
WS Res-B 10000
WR CP-3 3 Refill Storage C
WS Res-C 10000
WR CP-5 3 Refill Storage D
WS Res-D 10000
**
WR CP-6 24000 1 Senior Right
**
ED
** ! ! ! ! ! ! ! ! ! ! ! ! ! !
**
IN CP-1 2016 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000.
IN CP-2 2016 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000.
IN CP-3 2016 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000.
IN CP-4 2016 3000. 3000. 3000. 3000. 3000. 3000. 3000. 3000. 3000. 3000. 3000. 3000. 3000.
IN CP-5 2016 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000.
IN CP-6 2016 4000. 4000. 4000. 4000. 4000. 4000. 4000. 4000. 4000. 4000. 4000. 4000. 4000.
**
IN CP-1 2017 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
IN CP-2 2017 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
IN CP-3 2017 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
IN CP-4 2017 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
IN CP-5 2017 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
IN CP-6 2017 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

```

TABLES Input TIN File for Example 7

```

** 1 2 3 4
** 56789012345678901234567890123456789012345678
** ! ! ! ! ! ! ! ! ! !
2DIV 1 0 0 1 1
IDEN Diversion Right
2ROR 1 0 0 1 -1
2STO 1 0 0 2
2RSD 1 0 0 2
2RES 0 0 4 Res-A Res-B Res-C Res-D
2RES 10000. 10000. 10000. 10000.
4HRR 0 1 1 Diversion Right
ENDF

```


TABLES Output TOU File for Example 7

DIVERSIONS (AC-FT) FOR WATER RIGHT Diversion Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2016	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	47999.99
2017	4000.00	4000.00	3000.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11000.00
MEAN	4000.00	4000.00	3500.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	29499.99

RELEASES FROM RESERVOIR (AC-FT) FOR WATER RIGHT Diversion Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2016	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	24000.0
2017	4000.0	4000.0	3000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11000.0
MEAN	3000.0	3000.0	2500.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	17500.0

END-OF-MONTH STORAGE (AC-FT) FOR RESERVOIR Res-A

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2016	8000.0	8000.0	8000.0	7000.0	7000.0	7000.0	6000.0	6000.0	6000.0	5000.0	3000.0	3000.0	6166.7
2017	2000.0	2000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	333.3
MEAN	5000.0	5000.0	4000.0	3500.0	3500.0	3500.0	3000.0	3000.0	3000.0	2500.0	1500.0	1500.0	3250.0

END-OF-MONTH STORAGE (AC-FT) FOR RESERVOIR Res-B

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2016	10000.0	8000.0	8000.0	8000.0	7000.0	7000.0	7000.0	5000.0	5000.0	5000.0	5000.0	3000.0	6500.0
2017	3000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	250.0
MEAN	6500.0	4000.0	4000.0	4000.0	3500.0	3500.0	3500.0	2500.0	2500.0	2500.0	2500.0	1500.0	3375.0

END-OF-MONTH STORAGE (AC-FT) FOR RESERVOIR Res-C

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2016	10000.0	10000.0	8000.0	8000.0	8000.0	7000.0	7000.0	7000.0	5000.0	5000.0	5000.0	5000.0	7083.3
2017	2000.0	1000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	250.0
MEAN	6000.0	5500.0	4000.0	4000.0	4000.0	3500.0	3500.0	3500.0	2500.0	2500.0	2500.0	2500.0	3666.7

END-OF-MONTH STORAGE (AC-FT) FOR RESERVOIR Res-D

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2016	10000.0	10000.0	10000.0	9000.0	8000.0	7000.0	6000.0	6000.0	6000.0	5000.0	5000.0	5000.0	7250.0
2017	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0
MEAN	7500.0	7500.0	7500.0	7000.0	6500.0	6000.0	5500.0	5500.0	5500.0	5000.0	5000.0	5000.0	6125.0

STORAGE DRAWDOWN (AC-FT) FOR RESERVOIR Res-A

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2016	2000.0	2000.0	2000.0	3000.0	3000.0	3000.0	4000.0	4000.0	4000.0	5000.0	7000.0	7000.0	3833.3
2017	8000.0	8000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	9666.7
MEAN	5000.0	5000.0	6000.0	6500.0	6500.0	6500.0	7000.0	7000.0	7000.0	7500.0	8500.0	8500.0	6750.0

STORAGE DRAWDOWN (AC-FT) FOR RESERVOIR Res-B

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2016	0.0	2000.0	2000.0	2000.0	3000.0	3000.0	3000.0	5000.0	5000.0	5000.0	5000.0	7000.0	3500.0
2017	7000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	9750.0
MEAN	3500.0	6000.0	6000.0	6000.0	6500.0	6500.0	6500.0	7500.0	7500.0	7500.0	7500.0	8500.0	6625.0

STORAGE DRAWDOWN (AC-FT) FOR RESERVOIR Res-C

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2016	0.0	0.0	2000.0	2000.0	2000.0	3000.0	3000.0	3000.0	5000.0	5000.0	5000.0	5000.0	2916.7
2017	8000.0	9000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	9750.0
MEAN	4000.0	4500.0	6000.0	6000.0	6000.0	6500.0	6500.0	6500.0	7500.0	7500.0	7500.0	7500.0	6333.3

STORAGE DRAWDOWN (AC-FT) FOR RESERVOIR Res-D

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2016	0.0	0.0	0.0	1000.0	2000.0	3000.0	4000.0	4000.0	4000.0	5000.0	5000.0	5000.0	2750.0
2017	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0
MEAN	2500.0	2500.0	2500.0	3000.0	3500.0	4000.0	4500.0	4500.0	4500.0	5000.0	5000.0	5000.0	3875.0

END-OF-PERIOD RESERVOIR STORAGE AS A PERCENTAGE OF CAPACITY

$$\text{Percentage} = 100\% * (S - C2) / (C1 - C2) \quad \text{where}$$

S = end-of-month storage
C1, C2 = user defined top and bottom of storage zone

YEAR	MONTH	MEAN	Res-A	Res-B	Res-C	Res-D
2016	1	95.00	80.00	100.00	100.00	100.00
2016	2	90.00	80.00	80.00	100.00	100.00
2016	3	85.00	80.00	80.00	80.00	100.00
2016	4	80.00	70.00	80.00	80.00	90.00
2016	5	75.00	70.00	70.00	80.00	80.00
2016	6	70.00	70.00	70.00	70.00	70.00
2016	7	65.00	60.00	70.00	70.00	60.00
2016	8	60.00	60.00	50.00	70.00	60.00
2016	9	55.00	60.00	50.00	50.00	60.00
2016	10	50.00	50.00	50.00	50.00	50.00
2016	11	45.00	30.00	50.00	50.00	50.00
2016	12	40.00	30.00	30.00	50.00	50.00
2017	1	30.00	20.00	30.00	20.00	50.00
2017	2	20.00	20.00	0.00	10.00	50.00
2017	3	12.50	0.00	0.00	0.00	50.00
2017	4	12.50	0.00	0.00	0.00	50.00
2017	5	12.50	0.00	0.00	0.00	50.00
2017	6	12.50	0.00	0.00	0.00	50.00
2017	7	12.50	0.00	0.00	0.00	50.00
2017	8	12.50	0.00	0.00	0.00	50.00
2017	9	12.50	0.00	0.00	0.00	50.00
2017	10	12.50	0.00	0.00	0.00	50.00
2017	11	12.50	0.00	0.00	0.00	50.00
2017	12	12.50	0.00	0.00	0.00	50.00

RESERVOIR STORAGE DRAWDOWN DURATION

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	NUMBER OF PERIODS WITH DRAWDOWNS EQUALING OR EXCEEDING PERCENT OF ZONE STORAGE CAPACITY								
				0%	2%	5%	10%	25%	50%	75%	90%	100%
Res-A	3250.00	0.	10000.	24.	24.	24.	24.	21.	15.	12.	10.	10.
Res-B	3375.00	0.	10000.	24.	23.	23.	23.	20.	17.	11.	11.	11.
Res-C	3666.67	0.	10000.	24.	22.	22.	22.	19.	16.	12.	11.	10.
Res-D	6125.00	0.	10000.	24.	21.	21.	21.	19.	15.	0.	0.	0.

RESERVOIR STORAGE RELIABILITY

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING PERCENTAGE OF STORAGE CAPACITY								
				100%	98%	95%	90%	75%	50%	25%	10%	>0%
Res-A	3250.00	0.	10000.	0.0	0.0	0.0	0.0	12.5	41.7	50.0	58.3	100.0
Res-B	3375.00	0.	10000.	4.2	4.2	4.2	4.2	16.7	45.8	54.2	54.2	100.0
Res-C	3666.67	0.	10000.	8.3	8.3	8.3	8.3	20.8	50.0	50.0	58.3	100.0
Res-D	6125.00	0.	10000.	12.5	12.5	12.5	16.7	20.8	100.0	100.0	100.0	100.0

MONTHLY RELEASES FROM SYSTEM RESERVOIRS FOR WATER RIGHT Diversion Right

YEAR	MT	Res-A	Res-B	Res-C	Res-D
2016	1	2000.0	0.0	0.0	0.0
2016	2	0.0	2000.0	0.0	0.0
2016	3	0.0	0.0	2000.0	0.0
2016	4	1000.0	0.0	0.0	1000.0
2016	5	0.0	1000.0	0.0	1000.0
2016	6	0.0	0.0	1000.0	1000.0
2016	7	1000.0	0.0	0.0	1000.0
2016	8	0.0	2000.0	0.0	0.0
2016	9	0.0	0.0	2000.0	0.0
2016	10	1000.0	0.0	0.0	1000.0
2016	11	2000.0	0.0	0.0	0.0
2016	12	0.0	2000.0	0.0	0.0
2017	1	1000.0	0.0	3000.0	0.0
2017	2	0.0	3000.0	1000.0	0.0
2017	3	2000.0	0.0	1000.0	0.0
2017	4	0.0	0.0	0.0	0.0
2017	5	0.0	0.0	0.0	0.0
2017	6	0.0	0.0	0.0	0.0
2017	7	0.0	0.0	0.0	0.0
2017	8	0.0	0.0	0.0	0.0
2017	9	0.0	0.0	0.0	0.0
2017	10	0.0	0.0	0.0	0.0
2017	11	0.0	0.0	0.0	0.0
2017	12	0.0	0.0	0.0	0.0

Example 8 Focusing on Flow Switch *FS* Record Target Setting Capabilities

Examples 8 and 9 illustrate the flow switch *FS* record. The simple system of Example 8 has two control points and one diversion. The diversion at CP-1 is a function of the cumulative regulated flow during the current and preceding 11 months at CP-2. Regulated flow is selected as the flow switch variable *FSV* in *FS* record field 3. The monthly diversion target is 333.33 acre-feet/month if the 12-month cumulative regulated flow volume at CP-2 falls within the following range. Otherwise, the monthly diversion target is 1,000 acre-feet/month.

$$3,000 \text{ acre-feet} \leq \text{Cumulative Regulated Flow Volume} \leq 9,000 \text{ acre-feet}$$

Inclusion of the current month in the summation of a selected flow switch variable *FSV* is complicated by the fact that *FSV* quantities change during the priority sequence simulation computations. The parameter *FSI(FS,8)* in *FS* record field 15 provides options for including or excluding the current month in the *FSV* summation. *FSI(FS,8)* option 3 consists of simply excluding the current month. *FSI(FS,8)* options 1 and 2 include the current month. Options 1 versus 2 are slightly different if regulated flow is selected as the *FSV* in *FS* field 3 but are identically the same for any other choice of *FSV*. With regulated flow selected for the *FSV*, option 1 differs from option 2 only if the second pass option is activated by *PASS2* in *JO* record field 14 or *IFMETHOD* in *IF* record field 8. With the default *FSI(FS,8)* option 1, during the second pass, the regulated flow computed during the first pass is used. With *FSI(FS,8)* option 2, the latest regulated flow computed in the second pass is used just like for any other *FSV* variable.

FSI(FS,8) options 1 and 2 are the same for Example 8 since the second pass option is not activated. The blank *FS* record field 15 activates the default *FSI(FS,8)* option 1 in which the current month is included along with the 11 preceding months (*FS* record field 12) in totaling the cumulative *FSV* volume. The cumulative *FSV* volume consists of the summation of actual regulated flow volumes in the 11 preceding months plus, for the current month, the latest regulated flow in the water right priority sequence computations prior to this right. With no other senior rights in the example, the naturalized flow is the regulated flow in the current month.

SIM Input DAT File for Example 8

```
T1 WRAP-SIM Input File Exam8.DAT
T2 Example 8 from Appendix C of Reference Manual
T3 Illustrating Flow Switch FS Record
JD 4 2013 1 -1 -1
JO 3
CP CP-1 CP-2 NONE
CP CP-2 OUT NONE
**
WR CP-1 12000 Flow Switch
FS 1 CP-2 0.33333 1.0 3000. 9000. 1 0 0 11
ED
IN CP-1 2013 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000.
IN CP-2 2013 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000.
IN CP-1 2014 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
IN CP-2 2014 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
IN CP-1 2015 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000. 1000.
IN CP-2 2015 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000. 2000.
IN CP-1 2016 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
IN CP-2 2016 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
```

TABLES Input TIN File for Example 8

```

**** TABLES Input File Exam8.TIN
**** Example 8 from Reference Manual
2TAR  1  0  0  1  1
IDEN   Flow Switch
2DIV  1  0  0  1 -1
2REG  1  0  0  0  1
IDEN   CP-2
2REG  1  0  0  0 -1      2  12
ENDF

```

TABLES Output TOU File for Example 8

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT Flow Switch

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	12000.00
2014	1000.00	1000.00	333.33	333.33	333.33	333.33	333.33	333.33	333.33	1000.00	1000.00	1000.00	7333.31
2015	1000.00	333.33	333.33	333.33	333.33	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	9333.32
2016	1000.00	1000.00	1000.00	333.33	333.33	333.33	333.33	333.33	333.33	1000.00	1000.00	1000.00	7999.98
MEAN	1000.00	833.33	666.66	500.00	500.00	666.66	666.66	666.66	666.66	1000.00	1000.00	1000.00	9166.65

DIVERSIONS (AC-FT) FOR WATER RIGHT Flow Switch

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	12000.00
2014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	1000.00	333.33	333.33	333.33	333.33	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	9333.32
2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEAN	500.00	333.33	333.33	333.33	333.33	500.00	500.00	500.00	500.00	500.00	500.00	500.00	5333.33

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	12000.
2014	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2015	1000.	1667.	1667.	1667.	1667.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	14667.
2016	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	500.	667.	667.	667.	667.	500.	500.	500.	500.	500.	500.	500.	6667.

**REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP-2
MOVING TOTAL FOR 12 MONTHS**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	1000.	2000.	3000.	4000.	5000.	6000.	7000.	8000.	9000.	10000.	11000.	12000.	78000.
2014	11000.	10000.	9000.	8000.	7000.	6000.	5000.	4000.	3000.	2000.	1000.	0.	66000.
2015	1000.	2667.	4333.	6000.	7667.	8667.	9667.	10667.	11667.	12667.	13667.	14667.	103333.
2016	13667.	12000.	10333.	8667.	7000.	6000.	5000.	4000.	3000.	2000.	1000.	0.	72667.
MEAN	6667.	6667.	6667.	6667.	6667.	6667.	6667.	6667.	6667.	6667.	6667.	6667.	80000.

Example 9A Featuring FS and DI/IS/IP/IM Record Capabilities

Flow switch *FS* and drought index *DI*, *IS*, *IP*, and *IM* records are featured in Examples 9A and 9B. The *FS* records are used differently in Example 9A than in Example 9B. *FS* records are applied in Example 9A to assess the frequency of meeting certain criteria without actually connecting target setting decisions to the *FS* records. Example 9A illustrates application of WRAP to assess the likelihood or frequency that instream flow targets will be satisfied without activating specific actions in the model to achieve the targets. Conversely, in Example 9B, water management decisions occur within the simulation based on flow switch *FS* record specifications.

Example 9A focuses on developing 2FSV and 2FSC record tables along with other tables that display flow conditions. *FS* record cumulative flow switch variable *FSV* volumes and counts are automatically included on instream flow right output records in the *SIM* output OUT file that is read by the *TABLES* 2FSV and 2FSC record routines. Output records for *WR* record water rights do not *FSV* volumes and counts. Therefore, *IF* records are used to display the information of interest without actually activating instream flow targets. The *SIM* DAT file and *TABLES* TIN input files are reproduced as follows.

WRAP-SIM Input DAT File for Example 9A

```

T1 WRAP-SIM Input File Exam9A.DAT
T2 Example 9A from Appendix C of Reference Manual
T3 Flow Volumes and Counts Displayed with TABLES 2FSV and 2FSC Records
**      1      2      3      4      5      6      7      8
**345678901234567890123456789012345678901234567890123456789012345678
**      !      !      !      !      !      !      !      !      !      !
JD      4      2013      1      -1      -1
JO      3
**
CP CP-1      CP-2      NONE
CP CP-2      OUT      NONE
**
IF CP-2      1      Display FS-1
FS 1 2      1500. 2500.      11      1
**
IF CP-2      2      Display FS-2
FS 2 2      1500. 2500.      5 7 12      1
**
WR CP-2      1200.      3 8      Type 8 Right
**
IF CP-2      4      Display FS-3
FS 3 10      50. 300.      11      1 Type 8 Right
**
IF CP-2      5      Display FS-4
FS 4 10      50. 300.      5 7 12      1 Type 8 Right
**
WR CP-1      2400.      6      Reservoir
WS Res-A      10000.      0.1 1.0
**      !      !      !      !      !      !      !      !      !      !
DI      1      1      Res-A
IS      4      0.0 5000. 10000.
IP      0.0 50. 50.
IM      1 -1 -1 -1 -1 -1 -1 -1 -1 0 0 0
ED

```

WRAP-SIM Input DAT File for Example 9A (Continued)

IN	CP-1	2013	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
IN	CP-2	2013	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.
IN	CP-1	2014	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
IN	CP-2	2014	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
IN	CP-1	2015	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
IN	CP-2	2015	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
IN	CP-1	2016	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
IN	CP-2	2016	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TABLES Input TIN File for Example 9A

```

****      TIN File for Example 9A
****      1          2          3
****56789012345678901234567890123456
****      !      !      !      !      !      !      !      !
2NAT      1      0      0      0      1
IDEN      CP-2
2FSV      1      0      0      1      2
IDEN      Display FS-1      Display FS-2
2FSC      1      0      0      1      -2      0
2TAR      1      0      0      1      1
IDEN      Type 8 Right
2FSV      1      0      0      1      2
IDEN      Display FS-3      Display FS-4
2FSC      1      0      0      1      -2      0
2STO      1      0      0      0      1
IDEN      CP-1
2TAR      1      0      0      1      1
IDEN      Reservoir
ENDF

```

The only water right in the DAT file of Example 9A that actually affects water management decisions is the *WR* record right with the identifier *Reservoir*. This water right supplies a diversion target from stream flow at control point CP-1 supplemented as necessary by withdrawals from reservoir Res-A. An intermediate diversion target of 200 acre-feet/month is modified by a drought index defined by a set of *DI*, *IS*, *IP*, and *IM* records. The 200 acre-feet/month target is multiplied by a factor interpolated by *SIM* from the *IS/IP* record table.

The *IM* record specifies that the multiplier factor is set based on the storage contents of Res-A at the beginning of January and is applied during January through September. The drought index is not applied during October, November, and December. Res-A has a storage capacity of 10,000 acre-feet. The monthly diversion target of 200 acre-feet in January through September is multiplied by a factor set based on the storage contents at the beginning of January. The drought index multiplier factor varies linearly from 0.0 to 0.50 as the storage contents increases from 0.0 to 5,000 acre-feet. With storage contents at or above 5,000 acre-feet, the intermediate target of 200 ac-ft/month is multiplied by 0.50 to obtain 100 ac-ft/month. The diversion target during October, November, and December is 200 acre-feet/month. The simulated end-of-month storage contents of Res-A and associated diversion targets are tabulated in the last two tables in the *TABLES* output TOU file reproduced on the following pages.

No instream flow *IF* record targets are activated in the DAT file. Likewise, no *FS* record flow switches are actually activated. The only purpose served by the *IF* and *FS* input records is to record volumes and counts on the instream flow output records in the *SIM OUT* file that are read by the *TABLES 2FSV* and *2FSC* record routines. The default (blank) *FS* record field 9 (*FSI(FS,2)* = 0) indicates that the flow switch is not activated. The blank *IF* record field 3 (zero target amount) indicates there is no instream flow target specified.

The flow switch variable *FSV* is selected by in *FS* record field 3. Naturalized flow is the *FSV* for flow switches 1 and 2 connected to the *IF* records with identifiers *Display FS-1* and *Display FS-2*. The diversion target for the *WR* record with water right identifier *Type 8 Right* is the *FS* record flow switch variable *FSV* for flow switches 3 and 4 connected to the *IF* records with identifiers *Display FS-3* and *Display FS-4*.

The *WR* record with the water right identifier *Type 8 Right* has type 8 specified in *WR* record column 36. The only function performed by type 8 rights is to create a target that is used by other water rights. The 100 acre-feet/month diversion target for this *WR* record right is used as the flow switch variable *FSV* for flow switches 3 and 4 connected to the instream flow *IF* record rights *Display FS-3* and *Display FS-4*.

FS record 1 entered with *IF* record right *Display FS-1* accumulates naturalized flows at CP-2 over the current month and 11 preceding months. *FS* record 2 entered with *IF* record right *Display FS-2* accumulates naturalized flows at CP-2 over the current month and 5 preceding months but only for months 7 through 12 (July, August, September, October, November, and December). Naturalized flows at CP-2 are tabulated in the first table in the *TABLES* output file. The *2FSV* tables are the second and third tables in the *TABLES* output TOU file.

FS records 1 and 2 specified a range of naturalized flows defined by lower and upper bounds of 1,500 and 2,500 acre-feet/month. The corresponding *2FSC* tables are the 4th and 5th tables in the TOU file. These counts are the number of months during the specified periods that the monthly naturalized flow volume is between 1,500 and 2,500 acre-feet. For example, the *2FSC* table for *Display FS-1* shows a count of 7 months for May 2008. This means that the naturalized flow is between 1,500 and 2,500 acre-feet during 7 months of the 12-month period extending from June 2013 through May 2014. The *2FSC* table for *Display FS-2* shows a count of 1 month for May 2014. This means that the naturalized flow is between 1,500 and 2,500 acre-feet during 1 months of the 6-month period extending from December 2013 through May 2014, counting only July, August, September, October, November, and December.

FS record 3 entered with *IF* record right *Display FS-3* accumulates diversion targets over the current month and 11 preceding months. *FS* record 4 entered with *IF* record right *Display FS-4* accumulates diversion targets over the current month and 5 preceding months but only for months 7 through 12 (July, August, September, October, November, and December). The *FSV* diversion targets are tabulated in the sixth table in the TOU file. The corresponding *2FSV* and *2FSC* tables are the 7th, 8th, 9th, and 10th tables in the TOU file. The *2FSC* table for *Display FS-3* shows a count of 12 months for May 2014. This means that the diversion target for the type 8 *WR* record water right is between 50 and 300 acre-feet during all 12 months of the 12-month period extending from June 2013 through May 2014.

TABLES Output TOU File for Example 9A

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CP-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	24000.
2014	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2015	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	18000.
2016	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	10500.

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT Display FS-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	2000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	266000.0
2014	22000.0	20000.0	18000.0	16000.0	14000.0	12000.0	10000.0	8000.0	6000.0	4000.0	2000.0	0.0	132000.0
2015	1500.0	3000.0	4500.0	6000.0	7500.0	9000.0	10500.0	12000.0	13500.0	15000.0	16500.0	18000.0	117000.0
2016	16500.0	15000.0	13500.0	12000.0	10500.0	9000.0	7500.0	6000.0	4500.0	3000.0	1500.0	0.0	99000.0
MEAN	10500.0	15500.0	15000.0	14500.0	14000.0	13500.0	13000.0	12500.0	12000.0	11500.0	11000.0	10500.0	153500.0

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT Display FS-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	0.0	0.0	0.0	0.0	0.0	0.0	2000.0	4000.0	6000.0	8000.0	10000.0	12000.0	42000.0
2014	10000.0	8000.0	6000.0	4000.0	2000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30000.0
2015	0.0	0.0	0.0	0.0	0.0	0.0	1500.0	3000.0	4500.0	6000.0	7500.0	9000.0	31500.0
2016	7500.0	6000.0	4500.0	3000.0	1500.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22500.0
MEAN	4375.0	3500.0	2625.0	1750.0	875.0	0.0	875.0	1750.0	2625.0	3500.0	4375.0	5250.0	31500.0

FS RECORD FLOW COUNT FOR WATER RIGHT Display FS-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2014	11.0	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	66.0
2015	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2016	11.0	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	66.0
MEAN	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	72.0

FS RECORD FLOW COUNT FOR WATER RIGHT Display FS-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2014	5.0	4.0	3.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
2015	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2016	5.0	4.0	3.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
MEAN	2.5	2.0	1.5	1.0	0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	18.0

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT Type 8 Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2014	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2015	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2016	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
MEAN	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT Display FS-3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	100.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	13300.0
2014	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
2015	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
2016	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
MEAN	925.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14125.0

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT Display FS-4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	0.0	0.0	0.0	0.0	0.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	2100.0
2014	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
2015	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
2016	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
MEAN	375.0	300.0	225.0	150.0	75.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3225.0

FS RECORD FLOW COUNT FOR WATER RIGHT Display FS-3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2014	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
2015	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
2016	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
MEAN	9.2	9.5	9.7	10.0	10.2	10.5	10.7	11.0	11.2	11.5	11.7	12.0	127.5

FS RECORD FLOW COUNT FOR WATER RIGHT Display FS-4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2014	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
2015	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
2016	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
MEAN	3.7	3.0	2.2	1.5	0.7	0.0	1.0	2.0	3.0	4.0	5.0	6.0	32.2

EOP RESERVOIR STORAGE (AC-FT) AT CONTROL POINT CP-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2013	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0
2014	9900.0	9800.0	9700.0	9600.0	9500.0	9400.0	9300.0	9200.0	9100.0	8900.0	8700.0	8500.0	9300.0
2015	9400.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	9950.0
2016	9900.0	9800.0	9700.0	9600.0	9500.0	9400.0	9300.0	9200.0	9100.0	8900.0	8700.0	8500.0	9300.0
MEAN	9800.0	9900.0	9850.0	9800.0	9750.0	9700.0	9650.0	9600.0	9550.0	9450.0	9350.0	9250.0	9637.5

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT Reservoir

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
2014	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
2015	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
2016	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
MEAN	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00

Example 9B Featuring *FS* and *DI/IS/IP/IM* Record Capabilities

Examples 9A and 9B both illustrate the application of the flow switch *FS* records. These two examples use similar datasets with the difference being the purpose served by the *FS* records. Example 9A consists of assessing the extent to which flow switch criteria are satisfied without actually implementing the criteria in water management decisions in the *SIM* simulation. In Example 9B, *FS* records are actually used in setting instream flow targets. Thus, the *FS* records affect water management decisions in the model. Although illustrated here with two different simple examples, these two functions can be combined in the same DAT file in actual applications. A dataset can contain any number of *FS* records used in a variety of ways.

Like the other examples in Appendices B and C, simple rather than realistic numbers are adopted in Examples 9A and 9B. The objective of the examples is to provide input and output datasets that can be easily tracked manually so that users can conveniently explore the computational mechanics of the model.

The *WR* record water right with the identifier *Reservoir* is the same as Example 9B as in Example 9A. The intermediate diversion target of 200 acre-feet/month is modified by a drought index defined by a set of *DI*, *IS*, *IP*, and *IM* records in the same manner in both Examples 9A and 9B as described in Example 9A.

Example 9B includes an additional *WR* record right with the identifier *WR-FS-5*. Drought index 1 defined by the *DI*, *IS*, *IP*, and *IM* records is applied to water right *WR-FS-5* as well as water right *Reservoir*. After adjusting the initial 300 acre-feet/month diversion target using the drought index, the target water right *WR-FS-5* is then further adjusted using *FS* record flow switch 5. The diversion target is multiplied by either factor $F_{SX}(FS,1)$ or $F_{SX}(FS,2)$ from *FS* record fields 5 and 6 as designated by the flow switch.

The *WR* record in Examples 9A and 9B with the water right identifier *Type 8 Right* has type 8 specified in *WR* record column 36. The only function performed by type 8 rights is to create a target that is used by other water rights. The 100 acre-feet/month diversion target for this *WR* record right is used as the flow switch variable *F_{SV}* for flow switches 3 and 4 which are components of the instream flow *IF* record rights *Display FS-3* and *Display FS-4*.

Flow switch identifiers are set automatically by *SIM* but can also be entered in *FS* record field 2. In Example 9B, the five flow switch identifiers 1, 2, 3, 4, and 5 are entered in *FS* record column 6 (field 2). Likewise, the identifier 1 for the one drought index is found in *DI* record column 8 (field 2). The identifiers $F_{SCV}(wr)$ and $D_{INDEX}(wr)$ entered in *WR* record fields 10 and 11 reference the *FS* and *DI* records.

The $F_{SCV}(wr)$ of -5 in columns 59-60 of the *WR* record for water right *WR-FS-5* connects flow switch 5 of *IF* record water right *FS-5* to *WR* record water right *WR-FS-5*. The negative sign means that a flow switch multiplier factor rather than target volume is provided by *FS* record 5. The flow switch multiplier factor previously selected for *IF* record right *IF-FS-5* is applied to the diversion target developed for water right *WR-FS-5*. If the $F_{SCV}(wr)$ of -5 is changed to 5, the target previously computed for *IF* record right *IF-FS-5* would be adopted as the diversion target developed for *WR* record water right *WR-FS-5*.

SIM Input DAT File for Example 9B

```

T1 WRAP-SIM Input File Exam9B.DAT
T2 Example 9B from Appendix C of Reference Manual
T3 Application of FS Record Flow Switches and DI/IS/IP/IM Record Drought Index
**      1      2      3      4      5      6      7      8
**345678901234567890123456789012345678901234567890123456789012345678
**      !      !      !      !      !      !      !      !
JD      4      2013      1      -1      -1
JO      3
**
CP CP-1      CP-2
CP CP-2      OUT
**
IF CP-2      6000.      1      IF-FS-1
FS 1 2      1.0      0.0      1500.      2500.      1      11      1
**
IF CP-2      12000.      2      2      IF-FS-2
FS 2 2      1.0      0.0      1500.      2500.      1      5      7      12      1
**
WR CP-2      1200.      3      8      Type 8 Right
**
IF CP-2      18000.      4      2      IF-FS-3
FS 3 10      1.0      0.0      50.      300.      2      0      1      11      1 Type 8 Right
**
IF CP-2      24000.      5      2      IF-FS-4
FS 4 10      1.0      0.0      50.      300.      2      0      1      5      7      12      1 Type 8 Right
**
IF CP-2      30000.      6      2      IF-FS-5
FS 5 1      0.0      1.0      1.0      1.0      3      1      1
**
WR CP-1      2400.      7      1      Reservoir
WS Res-A      10000.      0.1      1.0
**
WR CP-1      3600.      8      -5      1      WR-FS-5
WS Res-A      10000.
**      !      !      !      !      !      !      !      !      !      !
DI      1      1      Res-A
IS      4      0.0      5000.      10000.
IP      0.0      50.      50.
IM      1      -1      -1      -1      -1      -1      -1      -1      0      0      0
ED
IN CP-1      2013      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.
IN CP-2      2013      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.
IN CP-1      2014      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN CP-2      2014      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN CP-1      2019      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.
IN CP-2      2015      1500.      1500.      1500.      1500.      1500.      1500.      1500.      1500.      1500.      1500.      1500.      1500.      1500.
IN CP-1      2016      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN CP-2      2016      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.

```

The five instream flow *IF* record rights *IF-FS-1*, *IF-FS-2*, *IF-FS-3*, *IF-FS-4*, and *IF-FS-5* have priorities of 1, 2, 4, 5, and 6, respectively. All five *IF* records set minimum instream flow targets at control point CP-2. *WRNUM(wr,10)* option 2 is entered in column 36 (field 7) of the *IF* records specifying that the largest target is adopted in comparing the alternative minimum instream flow targets. Each of the five *IF* record instream flow rights have a different *FS* record flow switch. The flow switch variable *FSV* (*FS* record field 3) is naturalized flow for *FS* records 1 and 2 and regulated flow for *FS* record 5. The diversion target for the *WR* record with water right identifier *Type 8 Right* is the flow switch variable *FSV* for *FS* records 3 and 4.

The criterion to be applied by a flow switch is selected by specifying one of three *FSI(FS,2)* options in column 52 of the *FS* record. Option 1 is adopted for *FS* records 1 and 2. Option 2 is adopted for *FS* records 3 and 4. Option 3 is adopted for *FS* record 5. The flow switch criteria specified by the five different *FS* records are described as follows.

Two alternative approaches are provided for applying the *FSV* volume range defined by the lower and upper bounds *FSX(FS,3)* and *FSX(FS,4)*. *FSI(FS,2)* option 1 is based on the total cumulative flow volume. Option 2 is based on counts and combines the integer count range defined by bounds *FSI(FS,3)* and *FSI(FS,4)* entered in *FS* fields 10 and 11 with the *FSV* volume range defined by *FSX(FS,3)* and *FSX(FS,4)* entered in *FS* fields 7 and 8. The number of months in which the flow volume for the month falls within the specified volume range is counted. The selection between the two multiplier factors depends on whether the count does or does not fall within the count range. The third *FSI(FS,2)* option defines *FSX(FS,3)* and *FSX(FS,4)* differently. *FSI(FS,2)* option 3 is based on whether and to what extent the *FSV* is increasing or decreasing.

Instream flow right *IF-FS-1* consists of the following *IF* and *FS* records.

IF	CP-2	6000.			1			IF-FS-1	
FS	1	2	1.0	0.0	1500.	2500.	1		11

The flow switch variable *FSV* is the cumulative total naturalized flow volume that occurs at control point CP-2 during the current and preceding 11 months (total of 12 months). The annual target of 6,000 acre-feet is distributed equally to each of the 12 months of the year resulting in an initial monthly instream flow target for each month of 500 acre-feet. In each month of the simulation, the 500 ac-ft target is multiplied by *FSX(FS,1)* of 1.0 if the cumulative naturalized flow falls within the following range and multiplied by *FSX(FS,2)* of 0.0 otherwise.

$$1,500 \text{ acre-feet} \leq \text{Cumulative Naturalized Flow Volume} \leq 2,500 \text{ acre-feet}$$

The 12 month period includes the current month and preceding 11 months, if there are 11 preceding months. However, prior to December 2007, preceding months number less than 11. Thus, as the current month progresses through the first 12 months (January-December 2007), the flows from January 2007 through the current month are summed. Beginning in December 2007, the summation includes a complete 12 months.

Simulation results recorded by *SIM* in the *OUT* output file includes cumulative *FSV* volumes and counts for instream flow *IF* record rights. Cumulative *FSV* volumes are organized by *TABLES* as specified by a 2FSV record. The naturalized flow at CP-2 during each month of 2007 and 2009 is 2,000 acre-feet/month. The naturalized flow is zero throughout 2008 and 2010. The 2FSV record table in the *TABLES* output *TOU* file presented on the following pages shows that the cumulative naturalized flow volume is 2,000 acre-feet in January 2007 increasing by 2,000 each month to 24,000 acre-feet/month in December 2007.

Instream flow right *IF-FS-2* consists of the following *IF* and *FS* records.

IF	CP-2	12000.		2	2			IF-FS-2	
FS	2	2	1.0	0.0	1500.	2500.	1		5 7 12

TABLES Input TIN File for Example 9B

```

****   TIN File for Example 9B
****   1         2         3         4         5         6         7         8
****567890123456789012345678901234567890123456789012345678901234
****   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !
2NAT   1   0   0   0   1
IDEN   CP-2
2REG   1   0   0   0  -1
2FSV   1   0   0   1   2
IDEN           IF-FS-1           IF-FS-2
2FSC   1   0   0   1  -2   0
2TAR   1   0   0   1   1
IDEN   Type 8 Right
2FSV   1   0   0   1   2
IDEN           IF-FS-3           IF-FS-4
2FSC   1   0   0   1  -2   0
2IFT   1   0   0   1   5
IDEN           IF-FS-1           IF-FS-2           IF-FS-3           IF-FS-4           IF-FS-5
2STO   1   0   0   0   1
IDEN   CP-1
2TAR   1   0   0   1   2
IDEN           Reservoir           WR-FS-5
ENDF

```

TABLES Output TOU File for Example 9B

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CP-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	24000.
2014	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2015	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	18000.
2016	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	10500.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	24000.
2014	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2015	500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	17000.
2016	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	625.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	10250.

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT IF-FS-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	2000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	24000.0	266000.0
2014	22000.0	20000.0	18000.0	16000.0	14000.0	12000.0	10000.0	8000.0	6000.0	4000.0	2000.0	0.0	132000.0
2015	1500.0	3000.0	4500.0	6000.0	7500.0	9000.0	10500.0	12000.0	13500.0	15000.0	16500.0	18000.0	117000.0
2016	16500.0	15000.0	13500.0	12000.0	10500.0	9000.0	7500.0	6000.0	4500.0	3000.0	1500.0	0.0	99000.0
MEAN	10500.0	15500.0	15000.0	14500.0	14000.0	13500.0	13000.0	12500.0	12000.0	11500.0	11000.0	10500.0	153500.0

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT IF-FS-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	0.0	0.0	0.0	0.0	0.0	0.0	2000.0	4000.0	6000.0	8000.0	10000.0	12000.0	42000.0
2014	10000.0	8000.0	6000.0	4000.0	2000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30000.0
2015	0.0	0.0	0.0	0.0	0.0	0.0	1500.0	3000.0	4500.0	6000.0	7500.0	9000.0	31500.0
2016	7500.0	6000.0	4500.0	3000.0	1500.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22500.0
MEAN	4375.0	3500.0	2625.0	1750.0	875.0	0.0	875.0	1750.0	2625.0	3500.0	4375.0	5250.0	31500.0

FS RECORD FLOW COUNT FOR WATER RIGHT IF-FS-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2014	11.0	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	66.0
2015	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2016	11.0	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	66.0
MEAN	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	72.0

FS RECORD FLOW COUNT FOR WATER RIGHT IF-FS-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2014	5.0	4.0	3.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
2015	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2016	5.0	4.0	3.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
MEAN	2.5	2.0	1.5	1.0	0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	18.0

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT Type 8 Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2014	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2015	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2016	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
MEAN	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT IF-FS-3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	100.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	13300.0
2014	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
2015	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
2016	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
MEAN	925.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14125.0

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT IF-FS-4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	0.0	0.0	0.0	0.0	0.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	2100.0
2014	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
2015	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
2016	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
MEAN	375.0	300.0	225.0	150.0	75.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3225.0

FS RECORD FLOW COUNT FOR WATER RIGHT IF-FS-3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2014	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
2015	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
2016	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
MEAN	9.2	9.5	9.7	10.0	10.2	10.5	10.7	11.0	11.2	11.5	11.7	12.0	127.5

FS RECORD FLOW COUNT FOR WATER RIGHT IF-FS-4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2014	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
2015	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
2016	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
MEAN	3.7	3.0	2.2	1.5	0.7	0.0	1.0	2.0	3.0	4.0	5.0	6.0	32.2

INSTREAM FLOW TARGETS (AC-FT) FOR WATER RIGHT IF-FS-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	500.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00
2014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	500.00
2015	500.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00
2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	500.00
MEAN	250.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	250.00	0.00	500.00

INSTREAM FLOW TARGETS (AC-FT) FOR WATER RIGHT IF-FS-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	500.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	1500.00
2014	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	1500.00
2015	500.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	1500.00
2016	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	1500.00
MEAN	250.00	0.00	0.00	0.00	500.00	0.00	500.00	0.00	0.00	0.00	250.00	0.00	1500.00

INSTREAM FLOW TARGETS (AC-FT) FOR WATER RIGHT IF-FS-3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	1500.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	2500.00
2014	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	1500.00
2015	500.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	1500.00
2016	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	1500.00
MEAN	500.00	0.00	0.00	0.00	500.00	0.00	500.00	0.00	0.00	0.00	250.00	0.00	1750.00

INSTREAM FLOW TARGETS (AC-FT) FOR WATER RIGHT IF-FS-4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	0.00	0.00	14000.00
2014	0.00	0.00	0.00	0.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	500.00	0.00	6500.00
2015	500.00	0.00	0.00	0.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	0.00	0.00	6500.00
2016	0.00	0.00	0.00	0.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	500.00	0.00	6500.00
MEAN	625.00	500.00	500.00	500.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	250.00	0.00	8375.00

INSTREAM FLOW TARGETS (AC-FT) FOR WATER RIGHT IF-FS-5

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	2000.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	29500.00
2014	2500.00	0.00	0.00	0.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	500.00	0.00	9000.00
2005	500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	28000.00
2016	2500.00	0.00	0.00	0.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	500.00	0.00	9000.00
MEAN	1875.00	1250.00	1250.00	1250.00	2250.00	2250.00	2250.00	1250.00	1250.00	1250.00	1500.00	1250.00	18875.00

EOP RESERVOIR STORAGE (AC-FT) AT CONTROL POINT CP-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2013	9900.0	9650.0	9400.0	9150.0	8900.0	8650.0	8400.0	8150.0	7900.0	7400.0	6900.0	6400.0	8400.0
2014	6150.0	6050.0	5950.0	5850.0	5750.0	5650.0	5550.0	5450.0	5350.0	5150.0	4950.0	4750.0	5550.0
2015	5655.0	5405.0	5155.0	4905.0	4655.0	4405.0	4155.0	3905.0	3655.0	3155.0	2655.0	2155.0	4155.0
2016	2047.9	2005.2	1962.6	1919.9	1877.2	1834.6	1791.9	1749.2	1706.5	1506.5	1306.5	1106.5	1734.5
MEAN	5938.2	5777.6	5616.9	5456.2	5295.6	5134.9	4974.2	4813.6	4652.9	4302.9	3952.9	3602.9	4959.9

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT Reservoir

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
2014	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
2015	95.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1495.00
2016	43.10	42.67	42.67	42.67	42.67	42.67	42.67	42.67	42.67	200.00	200.00	200.00	984.45
MEAN	84.52	85.67	85.67	85.67	85.67	85.67	85.67	85.67	85.67	200.00	200.00	200.00	1369.86

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT WR-FS-5

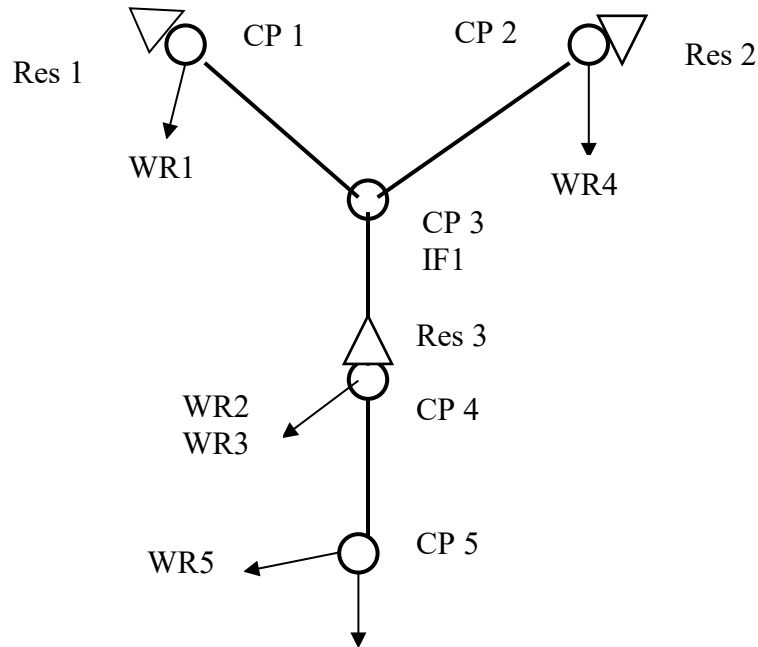
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2013	0.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	300.00	300.00	300.00	2100.00
2014	150.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	150.00
2015	0.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	300.00	300.00	300.00	2100.00
2016	64.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64.00
MEAN	53.50	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	150.00	150.00	150.00	1103.50

Beginning of Flow Switch Table in SIM Message MSS for Example 9B

2013	1	Display FS-1	FS 1	Bounds=	1500.0	2500.0	FSV=	2000.0	Count=	1	Target=	0.0
2013	1	Display FS-2	FS 2	Bounds=	1500.0	2500.0	FSV=	0.0	Count=	0	Target=	0.0
2013	1	Display FS-3	FS 3	Bounds=	50.0	300.0	FSV=	100.0	Count=	1	Target=	0.0
2013	1	Display FS-4	FS 4	Bounds=	50.0	300.0	FSV=	0.0	Count=	0	Target=	0.0
2013	2	Display FS-1	FS 1	Bounds=	1500.0	2500.0	FSV=	24000.0	Count=	2	Target=	0.0
2013	2	Display FS-2	FS 2	Bounds=	1500.0	2500.0	FSV=	0.0	Count=	0	Target=	0.0
2013	2	Display FS-3	FS 3	Bounds=	50.0	300.0	FSV=	1200.0	Count=	2	Target=	0.0
2013	2	Display FS-4	FS 4	Bounds=	50.0	300.0	FSV=	0.0	Count=	0	Target=	0.0
2013	3	Display FS-1	FS 1	Bounds=	1500.0	2500.0	FSV=	24000.0	Count=	3	Target=	0.0
2013	3	Display FS-2	FS 2	Bounds=	1500.0	2500.0	FSV=	0.0	Count=	0	Target=	0.0
2013	3	Display FS-3	FS 3	Bounds=	50.0	300.0	FSV=	1200.0	Count=	3	Target=	0.0
2013	3	Display FS-4	FS 4	Bounds=	50.0	300.0	FSV=	0.0	Count=	0	Target=	0.0
2013	4	Display FS-1	FS 1	Bounds=	1500.0	2500.0	FSV=	24000.0	Count=	4	Target=	0.0
2013	4	Display FS-2	FS 2	Bounds=	1500.0	2500.0	FSV=	0.0	Count=	0	Target=	0.0
2013	4	Display FS-3	FS 3	Bounds=	50.0	300.0	FSV=	1200.0	Count=	4	Target=	0.0
2013	4	Display FS-4	FS 4	Bounds=	50.0	300.0	FSV=	0.0	Count=	0	Target=	0.0
2013	5	Display FS-1	FS 1	Bounds=	1500.0	2500.0	FSV=	24000.0	Count=	5	Target=	0.0
2013	5	Display FS-2	FS 2	Bounds=	1500.0	2500.0	FSV=	0.0	Count=	0	Target=	0.0

Example 10 Featuring a Subordination Agreement

Example 10 illustrates the strategy outlined in the last section of Chapter 4 for combining *PX* and *BU* record features to model a subordination agreement. Water rights WR1 and WR2 in Example 10 are equivalent to water rights JJJ and SSS in Figure 4.4. Water right WR1 is junior to water right WR2 located downstream. However, according to the subordination agreement, the junior WR1 is not required to pass inflows through control point CP1 to maintain flows to meet requirements of WR2. WR3 is a backup right that serves the sole purpose of modeling the increases in stream flow depletions incurred by WR1 that must be mitigated by the subordinated senior right WR2. WR4, WR5, and IF1 are third-party rights that are not associated with the subordination agreement.



System Schematic for Example 10

SIM Naturalized Flow Input FLO File for Example 10

```

** WRAP-SIM Input File Exam10.FLO
** Example 10 from Appendix C of Reference Manual
**
** Naturalized Streamflow
**
IN  CP1  2015   600   600   600   600   600   600   600   600   600   600   600   600
IN  CP2  2015   300   300   300   300   300   300   300   300   300   300   300   300
IN  CP3  2015   900   900   900   900   900   900   1200  1200  1200  1200  1200  1200
IN  CP4  2015  1000  1000  1000   900   900   900   1200  1200  1200  1200  1200  1200
IN  CP5  2015  1400  1400  1400  1400  1400   900  1600  1600  1600  2000  2000  2000
IN  CP1  2016  4000  4000  4000   4000   0     0     0     200   200   200  4000  4000  4000
IN  CP2  2016  4000  4000  4000   300   300   300   300   300   300   300   300   300
IN  CP3  2016  4000  8000  8000   500   500   500   500   500   500  4300  4400  5000
IN  CP4  2016  4000  8000  8000   500   500   500   500   500   500   500   500   500
IN  CP5  2016  5000  9000  8000   900   900   900   900   900   500  1000  3000  5000

```

WRAP-SIM Input DAT File for Example 10

```

T1 WRAP-SIM Input File Exam10.DAT
T2 Example 10 from Appendix C of Reference Manual
** Simulation of a Subordination Agreement by Combining
** PX Record XCP and Dual Options and BU Record
**
**      1      2      3      4      5      6      7
**3456789012345678901234567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !
JD      2      2015      8      -1      -1      4
JO      -1
RO      2      Res 1      Res 3
**
CP      CP1      CP3      NONE
CP      CP2      CP3      NONE
CP      CP3      CP4      NONE
CP      CP4      CP5      NONE
CP      CP5      OUT      NONE
** -----
** Water rights WR1, WR2, and WR3 with PX records are associated
** with the subordination agreement.
**
** WR1 does not pass inflows for senior WR2 located downstream.
** Control point availability limit option is activated.
WR      CP1      7200.      1985      WR1
WS Res 1      5000.      .1      1.
PX      2      2      CP4
** -----
** WR2 is subordinated to the junior WR1.
** Dual pass option is activated to constrain flow depletions.
WR      CP4      6000.      1950      WR2
WS Res 3      8000.      .1      1.
PX      3
** -----
** WR3 is a backup right backing up WR1 from WR2 reservoir storage.
WR      CP4      2001      WR3
WS Res 3      8000.
BU      0      0      WR1
PX      2
** -----
** Water rights WR4, WR5, and IF1 are not associated
** with the subordination agreement.
**
WR      CP2      3600.      1978      WR4
WS Res 2      5000.      .1      1.
** -----
WR      CP5      4800.      1927      WR5
** -----
IF      CP3      1200.      1920      IF1
**      !      !      !      !      !      !      !      !
**      1      2      3      4      5      6      7
**3456789012345678901234567890123456789012345678901234567890123456789012
ED

```

WRAP-SIM Message MSS File for Example 10

```
WRAP-SIM MESSAGE FILE

*** Starting to read file Exam12.DAT
*** JD record was read.
*** JO record was read.
*** Reading RO records.
*** Starting to read UC records.
*** Finished reading UC records.
*** Starting to read CP records.
*** Finished reading CP records.
*** Starting to read IF/WR records.
*** Finished reading IF/WR records.
*** Finished reading file Exam12.DAT
*** Starting to open remaining files.
*** Opened file Exam12.FLO
*** Opened file Exam12.OUT
*** Finished opening text (non-DSS) files.
*** Finished ranking water rights in priority order.

*****
System components counted from input file:
    5 control points (CP records)
    5 primary control points (INMETHOD=1)
    0 control points with evap input (CPEV=blank)
    3 reservoirs
    1 instream flow rights (IF records)
    5 all water rights except IF rights (WR records)
    3 dual simulation rights
*****

*** Beginning annual loop.
***   5 IN and   0 EV records were read for the first year (2015).
*** End of input data trace.

*** Negative incremental flow adjustments are performed for the first year.
*** Rights with DUAL greater than zero are listed as follows:
      WR2           DUAL(wr)= 3    CP4       Res 3
      WR1           DUAL(wr)= 2    CP1       Res 1
      WR3           DUAL(wr)= 2    CP4       Res 3
*** Streamflow depletions from the initial simulation for DUAL of 3 or 4 are as follows.
Water Right: WR2
2015  500.0  500.0  500.0  500.0  500.0  500.0  500.0  500.0  500.0  500.0  500.0  500.0
2016  500.0  500.0  500.0  500.0  500.0  500.0  500.0  100.0  100.0  500.0  500.0  500.0
*** Initial simulation was completed.
*** The dual simulation option is activated by DUAL of 3 or 5
    on the PX or SO record of one or more rights or by JO field 11.
*** Beginning annual loop.
***   5 IN and   0 EV records were read for the first year (2015).
*** End of input data trace.

*** Negative incremental flow adjustments are performed for the first year.

Date:           09/09/2017
Beginning Time: 13:26:40
Ending Time:   13:26:40

***** Normal Completion of Program WRAP-SIM *****
```

TABLES Input TIN File for Example 10

```

COMM TABLES Input File Exam10.TIN
COMM Example 10 from Appendix C of Reference Manual
**      1      2      3      4      5
** 567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !      !      !      !
2TAR  1      0      0      1      3
IDEN  WR1                    WR2                    WR3
2SHT  1      0      0      1     -3
2DIV  1      0      0      1     -3
2XAV  1      0      0      1      1
IDEN  WR1
2STO  1      0      0      2      0
ENDF
    
```

TABLES Output File for Example 10

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT WR1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2015	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00
2016	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00
MEAN	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT WR2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2015	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00
2016	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00
MEAN	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT WR3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2015	300.00	300.00	300.00	400.00	400.00	500.00	200.00	200.00	200.00	200.00	200.00	200.00	3400.00
2016	0.00	0.00	0.00	0.00	0.00	0.00	200.00	100.00	100.00	500.00	0.00	0.00	900.00
MEAN	150.00	150.00	150.00	200.00	200.00	250.00	200.00	150.00	150.00	350.00	100.00	100.00	2150.00

DIVERSION SHORTAGES (AC-FT) FOR WATER RIGHT WR1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DIVERSION SHORTAGES (AC-FT) FOR WATER RIGHT WR2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DIVERSION SHORTAGES (AC-FT) FOR WATER RIGHT WR3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DIVERSIONS (AC-FT) FOR WATER RIGHT WR1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2015	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00
2016	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00
MEAN	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00

DIVERSIONS (AC-FT) FOR WATER RIGHT WR2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2015	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00
2016	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00
MEAN	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00

DIVERSIONS (AC-FT) FOR WATER RIGHT WR3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2015	300.00	300.00	300.00	400.00	400.00	500.00	200.00	200.00	200.00	200.00	200.00	200.00	3400.00
2016	0.00	0.00	0.00	0.00	0.00	0.00	200.00	100.00	100.00	500.00	0.00	0.00	900.00
MEAN	150.00	150.00	150.00	200.00	200.00	250.00	200.00	150.00	150.00	350.00	100.00	100.00	2150.00

INCREASE IN AVAILABLE STREAMFLOW RESULTING FROM PX RECORD CP LIMIT OPTION FOR WATER RIGHT WR1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2015	300.0	300.0	300.0	400.0	400.0	500.0	200.0	200.0	200.0	200.0	200.0	200.0	3400.0
2016	0.0	0.0	0.0	0.0	0.0	0.0	200.0	100.0	100.0	500.0	500.0	200.0	1600.0
MEAN	150.0	150.0	150.0	200.0	200.0	250.0	200.0	150.0	150.0	350.0	350.0	200.0	2500.0

END-OF-PERIOD STORAGE (AC-FT) FOR RESERVOIR Res 1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2015	4900.0	4800.0	4700.0	4600.0	4500.0	4400.0	4400.0	4400.0	4400.0	4400.0	4400.0	4400.0	4525.0
2016	5000.0	5000.0	5000.0	4400.0	3800.0	3200.0	2800.0	2300.0	1800.0	4800.0	5000.0	5000.0	4008.3
MEAN	4950.0	4900.0	4850.0	4500.0	4150.0	3800.0	3600.0	3350.0	3100.0	4600.0	4700.0	4700.0	4266.7

END-OF-PERIOD STORAGE (AC-FT) FOR RESERVOIR Res 3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2015	7700.0	7400.0	7100.0	6700.0	6300.0	5800.0	5600.0	5400.0	5200.0	5000.0	4800.0	4600.0	5966.7
2016	6300.0	8000.0	8000.0	8000.0	8000.0	8000.0	7800.0	7300.0	6800.0	6300.0	6300.0	6300.0	7258.3
MEAN	7000.0	7700.0	7550.0	7350.0	7150.0	6900.0	6700.0	6350.0	6000.0	5650.0	5550.0	5450.0	6612.5