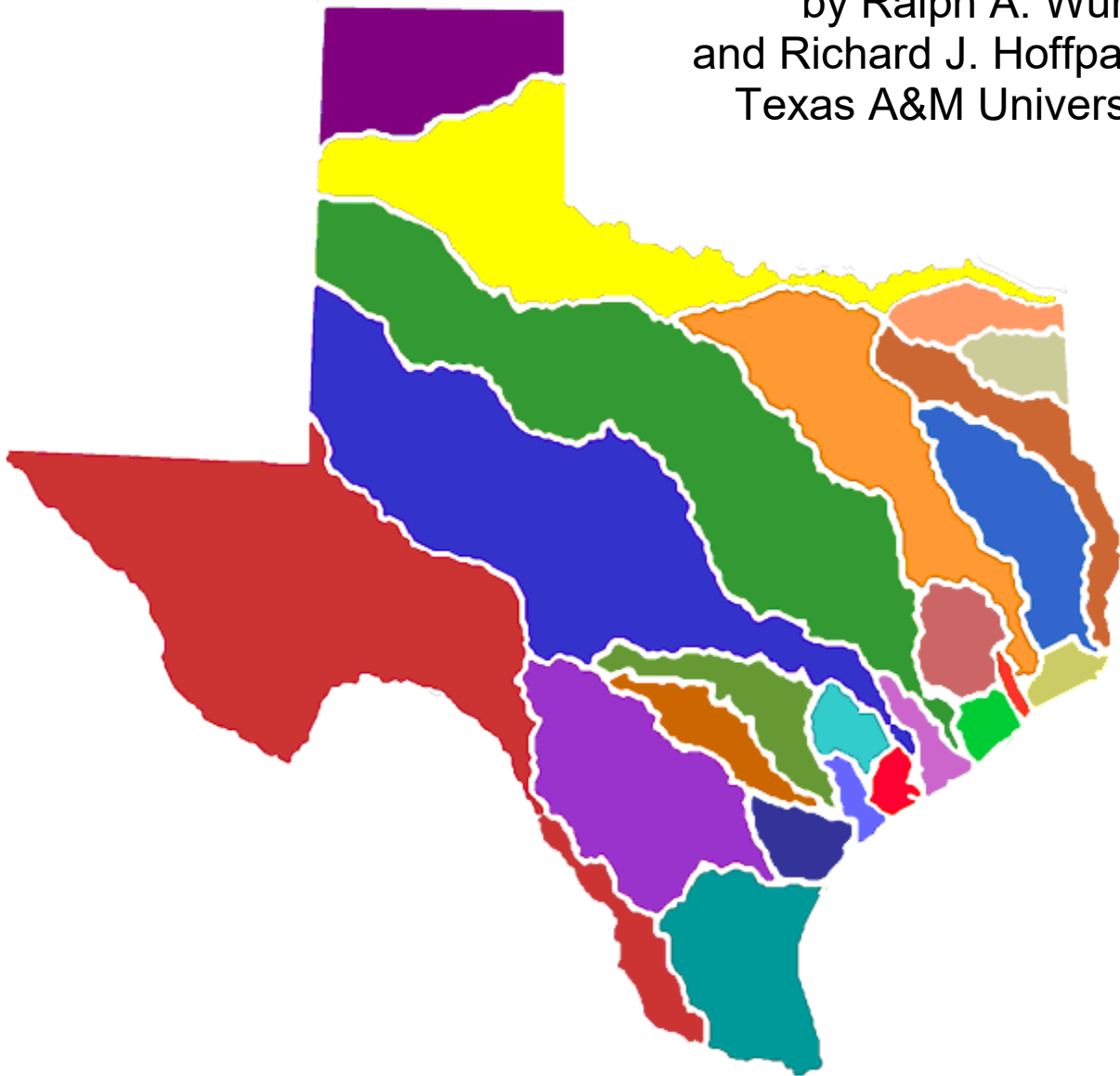


Water Rights Analysis Package (WRAP) Daily Modeling System

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by

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CHAPTER 1

WATER RIGHTS ANALYSIS PACKAGE (WRAP) MODELING SYSTEM

WRAP is a generalized modeling system providing flexible capabilities for analyzing river/reservoir system water resources development, management, control, allocation, and use. The Texas Commission on Environmental Quality (TCEQ) Water Availability Modeling (WAM) System combines WRAP with input datasets for the river basins of the state. The WRAP modeling system documented by the *Reference* and *Users Manuals* [1, 2] was originally developed based on a monthly computational time step. The TCEQ WAM System WRAP input datasets were developed and are routinely applied using a monthly time step. This *Daily Manual* documents an expanded version of WRAP that performs computations at an interval of one day and provides additional features for simulating flood control reservoir operations and environmental pulse flow standards. The daily WRAP software was originally designed for use also with other sub-monthly intervals but to date is fully operational and has been tested and applied only with a daily time step.

The expanded daily version of WRAP includes all of the capabilities of the monthly modeling system plus an array of additional major new features. Simulation computations are performed using a daily time interval. Monthly naturalized flow volumes are disaggregated to daily using daily flow pattern hydrographs. Methods for routing flow changes through river reaches are added for use with daily computational time steps. Calibration methods for determining routing parameters have been developed. Future days extending over a forecast period are considered in the simulation in determining both water availability from a supply perspective and remaining flood control channel flow capacity. The daily WRAP modeling system incorporates high pulse flow environment flow requirements and reservoir operations for flood control.

WRAP Documentation

This report explains the features added to WRAP to convert to a daily modeling system along with providing other additional water management modeling capabilities enabled by a daily time step. The expanded modeling capabilities outlined here build upon the original monthly WRAP organizational structure and methodologies. This *Daily Manual* supplements and extends the basic *Reference* and *Users Manuals*. The *Daily Manual* is written based on the premise that the reader is familiar with the information provided by the *Reference* and *Users Manuals*.

The WRAP programs listed in Table 1.1 are documented by the set of manuals listed on the next page and in the reference list on page 275. [References are cited by numbers in brackets.] The *Reference Manual* [1] provides a general overview of WRAP and a detailed explanation of monthly modeling capabilities. The *Users Manual* [2] covers the logistics of applying the WRAP programs *SIM*, *SIMD*, *TABLES*, and the Hydrologic Engineering Center (HEC) program *HEC-DSSVue*. The *Hydrology Manual* [3] documents the program *HYD* which is designed for developing monthly hydrology input data for the *SIM* simulation model. The *Salinity Manual* [4] covers program *SALT*. The *Fundamentals Manual* [5] is a condensed introduction to the basics of water availability modeling with the monthly *SIM* and *TABLES*.

This *Daily Manual* extends the *Reference Manual*, focusing on *SIMD* daily modeling capabilities. The *Daily Manual* appendices serve as the users manual for the WRAP programs *DAY* and *DAYH* used in the compilation of daily hydrology input for the *SIMD* simulation model.

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

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

Fundamentals of Water Availability Modeling with WRAP, TWRI TR-283, 10th Edition, July 2022. (*Fundamentals Manual*)

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

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

Water Rights Analysis Package (WRAP) Daily Modeling System, TWRI TR-430, Fifth Edition, July 2022. (*this Daily Manual*)

The WRAP daily modeling system has been significantly improved since its initial developmental test application to the Brazos River Basin and San-Jacinto-Brazos Coastal Basin Water Availability Model (WAM) [6]. An updated and expanded daily Brazos WAM [7] serves as a case study for developing, testing, and demonstrating the current version of the daily WRAP modeling system.

WRAP Programs

WRAP consists of the computer programs listed in Table 1.1 and manuals listed above. The programs are referenced by the filenames of the executable files tabulated in the second column of Table 1.1. The third column cites the manuals that document the programs.

Table 1.1
WRAP Programs

Program	Filename	Documentation	Function
WinWRAP	WinWRAP.exe	Fundamentals & Users	Microsoft Windows interface.
SIM	SIM.exe	Reference & Users Manuals	Monthly simulation model.
SIMD	SIMD.exe	Daily & Users Manuals	Daily simulation model.
TABLES	TAB.exe	Reference, Users, Daily, and Salinity Manuals	Post-simulation summary, reliability & frequency tables.
Salinity Simulation	SALT.exe	Salinity Manual	Salinity tracking model.
Monthly Hydrology	HYD.exe	Hydrology Manual	Monthly hydrology data.
Daily Flows	DAY.exe	Daily Manual	Daily flows input for <i>SIMD</i> .
Daily Hydrographs	DAYH.exe	Daily Manual	Daily flows input for <i>SIMD</i> .

Modeling applications combine the generalized WRAP programs with input datasets describing specific systems of rivers, reservoirs, other constructed facilities, and requirements for

water resources management, control, allocation, and use. Certain WRAP programs read files that have been created by other WRAP programs. The interface program *WinWRAP* facilitates connecting programs and data files within a Microsoft Windows operating system environment.

SIM simulates a river/reservoir water allocation/management system for input sequences of monthly naturalized flows and net evaporation rates. *SIM* is limited to a monthly time step. The expanded *SIMD* (D for daily) contains all of the capabilities of the monthly time step *SIM*, plus options related to environmental pulse flow requirements, reservoir operations for flood control, forecasting and routing, sub-monthly targets, and disaggregation of monthly naturalized stream flows to daily.

SIMD duplicates simulation results for datasets prepared for *SIM*. However, *SIM* is maintained as a separate program. *SIM* is complex, and addition to *SIMD* of sub-monthly time steps, flow forecasting and routing, flood control operations, pulse flow targets, and other features add significantly more complexity. *SIM* has been applied extensively as a component of the TCEQ WAM System. As a safeguard, maintenance of *SIM* allows ongoing applications of the TCEQ WAM System datasets that do not need the expanded modeling capabilities to continue with the basic *SIM* software without switching to the newer evolving and greatly expanded *SIMD*.

SIMD provides capabilities for performing a simulation using a daily computational time step with the daily results optionally being aggregated to monthly quantities. Monthly *SIMD* simulation results may be used by *TABLES* to perform conditional reliability analyses. The time parameters adopted to organize conditional reliability simulation sequences and present results are based on whole months, but the internal model computations may be performed daily. *SALT* can also use the aggregated monthly quantities provided by *SIMD* in a salinity tracking simulation.

HYD assists in developing or updating monthly naturalized stream flow and reservoir net evaporation rate data for the *SIM* hydrology input files. *HYD* capabilities for extending hydrologic periods-of-analysis include routines for synthesizing sequences of monthly naturalized flows from observed monthly precipitation and evaporation rates. *HYD* is covered in the *Hydrology Manual*.

Programs *DAY* and *DAYH* provide sets of computational routines that facilitate developing *SIMD* daily hydrology input that includes daily flow pattern hydrographs and values for routing parameters. *DAY* and *DAYH* are described in Appendices A and B, respectively, of this manual.

Program *TABLES* is used to organize, summarize, and analyze *SIM* and *SIMD* simulation results. Although some of the *TABLES* routines function only with monthly simulation results, the routines for developing reliability and frequency metrics and time series tabulations work with either daily or monthly simulation results. *TABLES* flood frequency analyses are applicable only to daily *SIMD* results. *TABLES* also includes features for summarizing *SIM/SIMD* input data.

The Hydrologic Engineering Center (HEC) data storage system (DSS) is an integral component of the WRAP modeling system. *HEC-DSSVue* [8] is employed to plot, tabulate, perform mathematical operations, and perform statistical analyses of time series of monthly or daily simulation results generated by *SIM*, *SIMD* or *TABLES*. DSS and *HEC-DSSVue* are also used to develop time series input datasets for *SIM* and *SIMD*. DSS and *HEC-DSSVue* provide comprehensive flexible capabilities for managing time series datasets including very large datasets. WRAP applications of DSS and *HEC-DSSVue* are outlined in Chapter 6 of the *Users Manual*.

WRAP Input and Output Files

The WRAP programs are generalized for application to any river/reservoir system, with input files being developed for the particular river basin of concern. The TCEQ WAM System includes monthly datasets for all of the river basins of Texas. Daily versions of the datasets are being developed. Application of WRAP in Texas involves modifying existing data files for a river basin of concern. Proposed water development projects and management strategies and changes in water use are added to the existing WAM System datasets to support particular studies and analyses. For applications outside of Texas where datasets have not been compiled, collecting data and creating input datasets for the river basin or region of concern represents the majority of the effort of a WRAP simulation study. The daily modeling capabilities outlined in this manual continue to use the datasets required for all WRAP applications, but additional data are required for some of the new features.

Table 1.2 lists the different types of WRAP input and output files. Table 1.3 is a matrix of computer programs and input/output files. All of the file types are listed including both those that are and are not relevant to the modeling features covered in this *Daily Manual*. Most of the files are discussed in the *Users* and *Reference Manuals*. Some are discussed in this *Daily Manual*. *SIM* and *SIMD* time series input data may all be stored in a DSS file with filename rootHYD.DSS or alternatively in separate DAT, FLO, EVA, TSF, FAD, RUF, and/or DIF text files. *SIM* and *SIMD* monthly and daily simulation results can be stored in either a DSS file or SUB and OUT files.

The input and output datasets which are in the format of text files can be read by Microsoft WordPad, NotePad, Word, and Excel and other editors such as NotePad++. *SIM* and *SIMD* also create and read binary DSS files. Program *TABLES* provides options to convert the simulation results produced by *SIM* and *SIMD* to DSS files. Program *Daily Flows (DAY)* converts flow data between binary DSS and text files. *HEC-DSSVue* performs various DSS data processing operations. The files are described in more detail in the *Users Manual*.

The names of the data files read and written by the WRAP programs are in the format *root.extension*. The root is an arbitrary name assigned by the model user. The 3-character extensions are set by naming conventions incorporated in the programs. The extensions listed in Tables 1.2 and 1.3 define the types of data contained in the files. File types are referred to by their extensions. For example, a DAT file has a filename with the extension DAT and consists of certain basic input data read by the programs *SIM* and *SIMD*. A FLO file has the filename extension FLO and contains monthly naturalized flows. All files for all programs may be named with the same filename root. Certain files used in a single execution of a program must have the same filename root. However, as discussed in the *Users* and *Fundamentals Manuals*, various options allow filename roots to differ based on user preferences.

The root assigned to *SIM* and *SIMD* hydrology files (root2.FLO, root2.EVA, root2.DIS, and root2HYD.DSS) may differ from the main input data file (root1.DAT). Thus, multiple DAT files reflecting different water management scenarios may be combined with the same FLO, EVA, and DIS files representing river basin hydrology. All of these files may also have the same filename root if the user prefers. In executing the WRAP programs from *WinWRAP*, the user provides the root and the software assigns the extensions automatically. Input files created with an editor must be saved with a filename with the appropriate three-character filename extension.

Table 1.2
Input and Output Files

SIM and SIMD Input Files

root1.DAT	required main input file containing all input <i>data</i> , except the voluminous hydrology related data contained in the following files
root2.DIS	flow <i>distribution</i> <i>FD</i> and <i>FC</i> and watershed parameter <i>WP</i> records
root2HYD.DSS	<i>hydrology</i> DSS file with monthly and daily time series input sequences
root2.FLO	inflow <i>IN</i> records with monthly naturalized <i>flows</i> (optional filename root.INF)
root2.EVA	<i>evaporation</i> <i>EV</i> records with monthly net evaporation-precipitation rates
root2.HYD	<i>IN</i> and <i>EV</i> records provided in a single <i>hydrology</i> file instead of FLO and EVA files
root2.TSF	monthly <i>target series</i> <i>file</i> with target series <i>TS</i> records
root2.FAD	monthly <i>flow adjustment</i> <i>FA</i> records for adjusting naturalized stream flows
root2.RUF	monthly <i>regulated-unappropriated</i> <i>RU</i> flow adjustment records
root2.HIS	monthly hydrologic index time series entered on <i>HI</i> records
root1.BES	<i>beginning</i> and/or <i>ending storage</i> listing activated by <i>JO</i> record field 5

Additional SIMD Input File

root2.DIF	<i>daily input</i> <i>file</i> containing routing parameters and other optional data
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SIM and SIMD Output Files

root1.MSS	<i>messages</i> reporting simulation progress and input data errors
root1.OUT	main simulation results <i>output</i> file read by <i>TABLES</i> and <i>SALT</i>
root1.SOU	main simulation results <i>output</i> file in columnar format
root1.DSS	simulation results output file in HEC-DSS (<i>data storage system</i>) binary format
root1.HRR	<i>hydropower</i> and <i>reservoir release</i> file read by <i>TABLES</i>
root1.YRO	<i>yield-reliability</i> output table presenting the results of a <i>FY</i> -record analysis
root1.CRM	conditional <i>reliability modeling</i> simulation results read by <i>TABLES</i>
root1.ZZZ	changes in stream flow availability in water rights sequence activated by <i>ZZ</i> record
root1.BES	<i>beginning</i> and/or <i>ending storage</i> listing activated by <i>JO</i> record field 5
root1.BRS	<i>beginning reservoir storage</i> listing activated by <i>JO</i> record field 6 to provide beginning reservoir storage for program <i>SALT</i> and <i>TABLES 5CR2</i> record routines

Additional SIMD Output Files

root1.SUB	<i>sub</i> -monthly (daily) time step simulation results
root1.AFF	<i>annual flood frequency</i> file with annual series of peak flow and storage
root1.SMM	<i>sub</i> -monthly <i>messages</i> reporting simulation parameters and optional information

Table 1.2
Input and Output Files (continued)

TABLES Input Files

root.TIN	required TABLES <i>input</i> file with specifications regarding tables to be developed
root.DAT	<i>SIM/SIMD</i> input DAT file
root.OUT	<i>SIM/SIMD</i> output OUT file
root.DSS	data storage system DSS file with any daily, monthly, or annual time series data
root.ZZZ	<i>SIM/SIMD</i> output ZZZ file
root.HRR	<i>SIM/SIMD</i> output HRR file
root.DIS	<i>SIM/SIMD</i> input DIS file
root.AFF	<i>SIMD</i> annual flood frequency output file with annual series of peak flow and storage
root.CRM	<i>SIM/SIMD</i> conditional reliability modeling output file
root.SFF	storage- flow-frequency file created by 5CR1 record and read by 5CR2 record
root.SAL	SALT salinity simulation results output file

TABLES Output Files

root.TOU	TABLES <i>output</i> file with the tables developed by the various routines
root.TMS	TABLES <i>message</i> file with tracking the computations and reporting input data errors
root.DSS	Hydrologic Engineering Center Data Storage System file read by <i>HEC-DSSVue</i>
root.SFF	storage- flow-frequency file created by 5CR1 record and read by 5CR2 record

Monthly Hydrology *HYD* Input Files

root.HIN	HYD file with all <i>input</i> data not included in the following hydrology files
root.FLO	inflow <i>IN</i> records with stream flows
root.EVA	evaporation <i>EV</i> records with net evaporation-precipitation rates
root.DIS	flow distribution <i>FD & FC</i> and watershed parameter <i>WP</i> records
root.HYD	<i>IN</i> and <i>EV</i> records in single hydrology file in modified format
root.DSS	Data Storage System file of stream flows and evaporation-precipitation depths
Precipitation.PPP	statewide TWDB quadrangle monthly precipitation dataset
Evaporation.EEE	statewide TWDB quadrangle monthly evaporation dataset

Monthly Hydrology *HYD* Output Files

root.HOT	HYD <i>output</i> file with all output not included in the following files
root.HMS	HYD <i>message</i> file tracking the computations and reporting input data errors
root.FLO	inflow <i>IN</i> records with naturalized stream flows
root.EVA	evaporation <i>EV</i> records with net evaporation-precipitation rates
root.DSS	Data Storage System file of stream flows and evaporation-precipitation depths

Table 1.2
Input and Output Files (continued)

Daily Flows *DAY* and Daily Hydrographs *DAYH* Input Files

root.DIN	main <i>DAY</i> input file
root.FLO	input file of monthly <i>flows</i> in either <i>IN</i> record or columnar format
root.DCF	input file of <i>daily flows</i> in either <i>DF</i> record or columnar format
root.DSS	input file of daily and monthly flows as DSS records

Daily Flows *DAY* and Daily Hydrographs *DAYH* Output Files

root.DAY	<i>DAY</i> output file
root.DMS	<i>DAY</i> message file
root.DSS	<i>SIMD</i> input file of daily and monthly flows as DSS records

SALT Input Files

root.SIN	required salinity <i>input</i> file with concentrations or loads of entering flows
root.DAT	required main <i>SIM/SIMD</i> input file from which <i>CP</i> records are read
root.OUT	required main <i>SIM/SIMD</i> <i>output</i> file with simulation results
root.BRS	<i>beginning reservoir storage</i> file created by <i>SIM/SIMD</i> and read by <i>SALT</i> to provide beginning reservoir storage if specified by <i>JC</i> record field 8
root.BRC	<i>beginning reservoir concentration</i> file created by <i>SALT</i> and also read by <i>SALT</i> as specified by <i>JC</i> record field 9

SALT Output Files

root.SAL	<i>salinity</i> simulation results read by <i>TABLES</i>
root.SMS	salinity <i>message</i> file with simulation trace, error and warning messages, and intermediate and summary simulation results tables
root.BRC	<i>beginning reservoir concentration</i> file created and read by <i>SALT</i>

Table 1.3
Matrix of Input and Output Files and Programs

File Type	File Function	WRAP Programs					
		SIM	SIMD	SALT	TABLES	HYD	DAY
<u><i>Main Required Input File for Each Program</i></u>							
DAT	<i>SIM</i> and <i>SIMD</i> input data file	input	input		input		
SIN	<i>SALT</i> input file			input			
TIN	<i>TABLES</i> input file				input		
HIN	<i>HYD</i> input file					input	
DIN	<i>DAY</i> input file						input

Table 1.3 (Continued)
Matrix of Input and Output Files and Programs

File Type	File Function	WRAP Programs					
		SIM	SIMD	SALT	TABLES	HYD	DAY
<u>Hydrology Input Data</u>							
FLO	<i>IN</i> record naturalized flows	input	input			in&out	in&out
EVA	<i>EV</i> record net evaporation	input	input			in&out	
DSS	DSS file with time series data	input	input		in&out	in&out	in&out
DIS	flow distribution parameters	input	input		input	input	
HYD	hydrology <i>IN</i> and <i>EV</i> records	input	input			input	
FAD	flow adjustments	input	input				
HIS	drought indices or other data	input	input				
DIF	daily input data		input				
DCF	daily flow data						in&out
<u>Main Simulation Results Output File for Each Program</u>							
OUT	<i>SIM</i> and <i>SIMD</i> main output file	output	output	input	input	input	
CRM	conditional reliability model file	output	output		input		
SOU	results in columnar tables	output	output				
SUB	<i>SIMD</i> sub-monthly time step file		output		input		
SAL	<i>SALT</i> main output file			output	input		
TOU	<i>TABLES</i> main output file				output		
DSS	DSS file with simulation results	output	output		in&out		
DAY	<i>DAY</i> main output file						output
<u>Message File for Each Program</u>							
MSS	<i>SIM</i> and <i>SIMD</i> message file	output	output				
SMM	<i>SIMD</i> sub-monthly message file		output				
SMS	<i>SALT</i> message file			output			
TMS	<i>TABLES</i> message file				output		
HMS	<i>HYD</i> message file					output	
DMS	<i>DAY</i> message file						output
<u>Special Purpose Files</u>							
TSF	target series file	input	input				
HRR	hydropower and reservoir release	output	output		input		
YRO	yield reliability output	output	output				
ZZZ	priority sequence flows	output	output		input		
BES	beginning/ending storage	in&out	in&out				
BRS	beginning reservoir storage	output	output	input	input		
BRC	beginning reservoir concentration			in&out			
SFF	storage-flow-frequency array				in&out		
AFF	annual flood frequency		output		input		

Note: The term "in&out" indicates that files may be either read as input or created as output.

Scope and Organization of this Manual

This manual explains WRAP features providing capabilities for simulation of flood control reservoir system operations, simulation of high pulse flow components of environmental flow standards, and options related to adoption of daily computational time steps that include monthly-to-daily disaggregation of flows and demand targets and flow forecasting and routing.

Chapters 2, 3, 4, and 10 outline the *SIMD* features used to convert from a monthly to a daily simulation model. Chapter 2 outlines the general framework of the daily model and options for monthly-to-daily disaggregation of naturalized river flows, demand targets, and other variables. Chapter 3 focuses on flow forecasting and routing methods and their integration into the overall volume accounting framework. Calibration of routing parameters is explained in Chapter 4. A summary overview of the daily WRAP modeling system is presented as Chapter 10.

A daily time step can be useful in modeling all aspects of water management including water supply and hydropower. However, the daily modeling capabilities are particularly relevant for simulating flood control operations and environmental instream flow requirements including high pulse flows. Simulation of flood control reservoir operations is discussed in Chapters 5 and 7. Features for modeling and analysis of pulse flow environmental instream flow standards are described in Chapters 6 and 8.

Chapters 7, 8, and 9 consist of examples that illustrate the modeling capabilities presented in the Chapters 2, 3, 5, and 6. The example presented in the *Fundamentals Manual* is expanded in Chapter 7 to include converting the monthly model to a daily time step and adding reservoir flood control operations. Environmental flow standards are added in Chapter 8. Frequency analyses of annual series from a daily *SIMD* simulation are performed in Chapter 9.

WRAP is applicable to systems covering the full range of complexity from studying operation of a single reservoir to investigations of river basins with hundreds of water users and hundreds of reservoirs operated for an array of purposes. The *Fundamentals Manual* example, which is expanded in Chapters 7, 8, and 9 of this *Daily Manual*, was adapted from the TCEQ WAM System dataset for the Brazos River Basin, which has about 700 reservoirs and 3,800 control points [7]. The simplified example designed for illustrative purposes is reduced to a system of six reservoirs, 11 control points, and hypothetical water management and use requirements.

Input records for *SIMD* daily features and the daily routines in *TABLES* are explained in Chapters 4 and 5 of the *Users Manual*. The DSS data storage system and *HEC-DSSVue* are described in Chapter 6 of the *Users Manual*. Appendices A and B of this *Daily Manual* provide instructions for preparing input records for *DAY* and *DAYH*, respectively.

This *Daily Manual* supplements the *Reference Manual* to cover the additional capabilities incorporated in *SIMD* that are not included in *SIM*. The *Daily Manual* also documents the pre-simulation daily hydrology data compilation programs *DAY* and *DAYH*. The ten chapters and two appendices of this manual cover the following topics.

Chapter 1. WRAP is comprised of computer programs, data files, and manuals. This first chapter provides a general overview of the monthly and daily versions of the modeling system.

Chapter 2. The general framework of the daily modeling system and the alternative methods for subdividing monthly naturalized flow volumes and water use targets into daily quantities in a *SIMD* daily simulation are described in Chapter 2.

Chapter 3. In a monthly *SIM* simulation, the effects of water management/regulation/use on stream flows are assumed to propagate through the river system within the month. However, in modeling a large river system with a daily time step, lag and attenuation effects are important and greatly complicate the simulation model. Flow routing and forecasting methods and their incorporation within the *SIMD* water accounting computations are described in Chapter 3. Options for dealing with negative incremental stream flows are also outlined in Chapter 3.

Chapter 4. The WRAP programs *DAY* and *DAYH* described in Appendices A and B employ calibration techniques described in Chapter 4 for determining values for the lag and attenuation parameters for the flow routing methods described in Chapter 3.

Chapter 5. The daily model provides the framework required to model flood mitigation. Additional new *SIMD* simulation features model any number of flood control reservoirs operated either individually or as multiple-reservoir systems to reduce flooding at 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. *SIMD* rules for operating reservoirs during floods also reflect flow capacities of dam outlet structures.

Chapter 6. *SIMD* features for modeling Senate Bill 3 (SB3) environmental flow standards (EFS) are explained in Chapter 6 within the framework of modeling water rights in general, but the chapter focuses particularly on high pulse flows. SB3 environmental flow standards include subsistence, base, and high pulse flow components. High pulse flows can be modeled only in a *SIMD* daily, not *SIM* monthly, simulation and are a focus of Chapter 6.

Chapter 7. The example in the *Fundamentals Manual* is converted to daily and reservoir flood control operations are added, illustrating the concepts presented in Chapters 2, 3, and 5.

Chapter 8. Senate Bill 3 (SB3) environmental flow standards (EFS) are added to the example developed in the preceding Chapter 7, illustrating the methods presented in Chapter 6 of this *Daily Manual* and Chapter 4 of the *Reference Manual* for modeling subsistence, base, and high flow components of SB3 EFS in both daily and monthly simulations.

Chapter 9. Frequency analyses methods covered in the *Reference, Users, Fundamentals,* and *Daily Manuals* are fundamental to WRAP. Chapters 7 and 8 include conventional *TABLES* frequency analyses of *SIMD* simulation results. Chapter 9 focus specifically on analyses of annual series of daily *SIMD* simulation quantities. The examples in Chapter 9 include frequency analyses of annual series of 7-day low flow volumes and annual series of reservoir storage peaks from *SIMD* daily simulation results.

Chapter 10. Key aspects of the daily WRAP are discussed from a broad overview perspective.

Appendices A and B. Instructions for applying the WRAP programs *DAY* and *DAYH* are provided in Appendices A and B. The routing parameter calibration methods implemented in *DAY* and *DAYH* are explained in Chapter 4.

CHAPTER 2 DAILY MODELING SYSTEM

The WRAP daily modeling system was developed by expanding the programs *SIM* and *TABLES* to incorporate additional features and creating new programs for compiling *SIMD* input data. The simulation model *SIMD* (*D* for daily) consists of the monthly *SIM* in its entirety along with the major additional features described in this manual. The post-simulation program *TABLES* provides options for developing frequency and reliability metrics using either daily time step simulation results or aggregated monthly results. *Daily Flow* programs (*DAY* and *DAYH*) contain routines for calibration of *SIMD* routing parameters and compilation of daily pattern hydrographs for use in the *SIMD* monthly-to-daily flow disaggregation computations.

The WRAP simulation model *SIMD* was originally designed to allow each of the 12 months of the year to be divided into an integer number of time steps, up to a maximum limit of 32 per month. However, the day is the only sub-monthly interval for which *SIMD* is now fully operational. Other sub-monthly intervals are not used. With the daily time step, each month is subdivided into 31, 30, 29 (leap year February), or 28 days.

A conventional monthly simulation may be performed with *SIMD* with the same input datasets used with *SIM*. Supplemental input is added to apply the *SIMD* sub-monthly features. Naturalized river flows generate most of the daily or sub-monthly variability in the simulation. Flow forecasting and routing are incorporated in the computations to simulate lag and attenuation effects. All simulation result variables are computed by *SIMD* for each time step, but the daily quantities may be summed to monthly amounts. *TABLES* organizes *SIMD* simulation results and develops frequency and reliability tables using either daily *SIMD* results or aggregated monthly amounts. The two pre-simulation utility programs described in Appendices A and B facilitate developing *SIMD* routing parameters and other daily flow related input.

The daily features of the *WRAP-SIMD* simulation model include:

- alternative methods for disaggregating naturalized monthly flows to daily that range in complexity from a linear interpolation routine that requires no additional input data to methodologies that reproduce the daily variability exhibited by sequences of daily flows or flow patterns provided as model input
- option for using an input dataset of daily naturalized flows directly without monthly naturalized flows and thus without disaggregating monthly naturalized flows to daily
- alternative options for varying diversion, hydropower, and instream flow targets over the daily time steps within each month
- tracking of high pulse flows in conjunction with SB3 environmental instream flow standards
- methods for routing of stream flow adjustments
- determination of current day available stream flow for *WR* record water rights based on a forecast simulation over a future forecast period and reverse routing
- forecasting of remaining channel capacity for *FF/FR* record flood control operations
- simulation of reservoir flood control operations
- aggregation of daily simulation results to monthly quantities and recording of simulation results at both daily and/or monthly time steps

Modeling with Daily Versus Monthly Time Steps

Most reservoir/river system models use either a monthly or daily time step. The effects of computational time step choice on simulation results vary with different modeling applications. Flow averaging over longer time intervals tends to over-estimate capabilities for meeting requirements for water supply, environmental instream flow, hydroelectric power, and flood control. Accurate modeling of flood control operations is particularly difficult with a time step much greater than a day due to the extreme fluctuations in flow rates over short time spans associated with flood events. The effects of adopting a time interval of finite length on model results related to capabilities for meeting water supply, hydropower, and environmental instream flow requirements depend largely on the reservoir storage capacities available for mitigating flow fluctuations. Choice of time interval tends to affect reliability estimates for run-of-river diversion and instream flow targets much more than if there is reservoir storage to mitigate flow fluctuations. However, simulation results for systems with large reservoirs may also be affected by the choice of time interval.

A monthly interval provides adequate modeling accuracy for many common applications, while facilitating development and management of input datasets. A daily time step may improve the accuracy of a simulation though accuracy is not necessarily improved in all cases. A daily time step significantly increases the difficulty of compiling and managing input data. A daily interval greatly increases the effort required to develop multiple-decade-long sequences of naturalized stream flows at numerous locations. Flow forecasting and routing considerations are modeled in greater detail and correspondingly greater complexity with a daily time step than with a monthly interval, requiring specification of forecast periods and routing parameters.

The following considerations are addressed in this section.

- Flow rates that vary continuously over time in the real world are modeled as volumes occurring during discrete time intervals. Thus, comparisons of stream flow rates with water management/use targets in the model are based on total volumes during finite time intervals rather than instantaneous rates at points in time.
- In a monthly time step model, the effects of reservoir releases and water management/regulation/use actions on stream flows at downstream locations are assumed to propagate through the system within the same month, precluding flow forecasting and routing computations. However, flow forecasting and routing are important in typical modeling applications based on a daily time step.

Instantaneous Flow Rate versus Mean Flow Rate for a Time Interval

A hydrograph of instantaneous stream flow rates at a location on a river over a six-month period is plotted in Figure 2.1. A constant target flow rate is also plotted. This target could be either a minimum instream flow requirement or a diversion demand. The flow rate above which flood damages begin to occur is also shown. The river flow, instream flow or diversion target, and maximum non-damaging flood level are instantaneous flow rates that could be expressed in m^3/s , ft^3/s , or any other units of discharge. The flow volume during any specified time interval is represented by the area under the flow plot. For example, the total river flow during the six-month

period may be computed as the area under the stream flow hydrograph during January through June. Likewise, the total volume of the target during the six-month period is represented by the rectangular area under the plot of the instantaneous target discharge rate extending from January through June. A volume occurring during a specified time interval may be expressed as a mean flow rate during the interval in units such as m^3/s , thousand m^3/day , thousand $m^3/month$, million $m^3/year$, ft^3/s , acre-feet/day, acre-feet/month, or acre-feet/year.

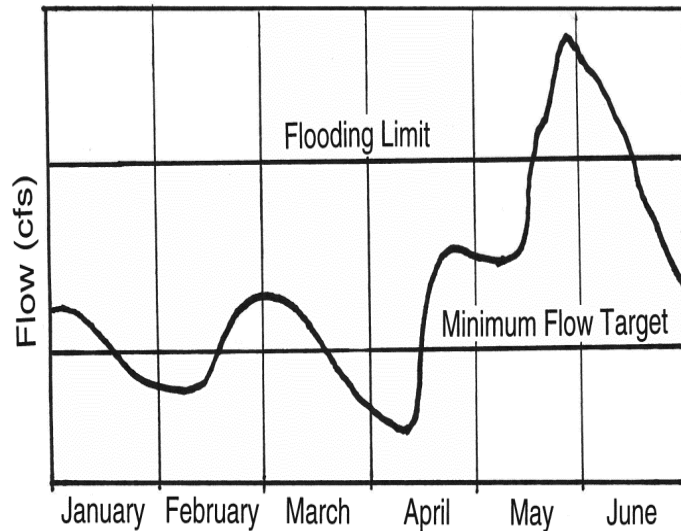


Figure 2.1 Stream Flow Hydrograph and Water Management Targets

Figure 2.1 illustrates the significance of adopting a daily versus monthly time interval. Assume that the target plotted in Fig. 2.1 is a constant minimum instream flow requirement. The stream flow hydrograph is the regulated flow at that location. If a monthly computational time interval is adopted, both the instream flow target and stream flow are expressed in terms of flow volume (area under the plots) in each month. The stream flow volume exceeds the instream flow target in each of the six months, with no failures to meet the target. However, results change significantly if a daily time step is adopted. Failures to meet the instream flow target occur during the last 15 days of January and first 15 days of February and during the last 14 days of March and first 15 days of April. With a monthly time interval, the instream flow target is satisfied 100 percent of the time during this six-month period. With a model with a daily computational time interval, the instream flow target is satisfied 67 percent of the time.

Now assume that the target is a water supply diversion right and the stream flow hydrograph is the stream flow available to the diversion right. For a run-of-river diversion, the period reliability is 100 percent and 67 percent, respectively, for a monthly and daily time interval. If the diversion target is supplied by stream flow supplemented as necessary by releases from one or more reservoirs located upstream, the amount of water withdrawn from reservoir storage will vary depending on the time step adopted. For a monthly time step, the entire demand is met from stream flow with no releases from reservoir storage. With a daily time step, portions of the demand during January, February, March, and April are met by releases from storage leaving less water in storage for future months. If the water supply diversion is lakeside directly from a reservoir, the

choice of monthly versus daily time step is less significant. The reservoir storage mitigates the effects of flow fluctuations during the month, storing excess stream flow and supplying the diversion target as necessary. The model time step becomes more significant during months in which the reservoir is empty for a portion of the month.

The flood level shown in Fig. 2.1 is the river flow level above which damages to properties or structures occur. With a monthly time interval, the mean stream flow rate each month is less than the mean monthly non-damaging flood discharge for each of the six months. A monthly time interval indicates no flooding. With a daily computational time step, the non-damaging flood level is exceeded during 30 days in May-June. Reservoir operations for flood control are based on storing inflows as necessary to prevent flows from exceeding the maximum non-damaging flow limits at downstream locations. Thus with a flood control reservoir, a daily time interval in Fig. 2.1 results in storage of flood waters, but a monthly time interval does not.

The Fig. 2.1 example illustrates the approximations involved in averaging flow rates over a monthly time interval. River flows may fall well below instream flow requirements for several days even though high flows in other days of the month result in the mean monthly stream flow being above the instream flow target. Reservoir storage plays a significant role in mitigating the effects of alternative choices of time interval. Although this discussion focuses on monthly versus daily time intervals, flow fluctuations during a day may also be significant. Flood flows may vary greatly over a period of an hour or several hours. However, the day and month are probably the two alternative time intervals that are most pertinent for most typical WRAP applications. The impacts of the choice of computational time interval on the accuracy of the model depend on the circumstances of the modeling application.

Flow Forecasting and Flow Routing

In a real-world river basin, time is required for the effects of diversions, return flows, and reservoir refilling and releases at an upstream location to propagate to downstream locations. River flows diverted or stored by a particular water user today may diminish the flows available to other water users located further downstream tomorrow or several days in the future. Likewise, flow travel times for reservoir releases or diversion return flows to reach other downstream locations may be several days, perhaps a week or longer. Thus, water supply capabilities are affected by earlier upstream activities. Flood control reservoir operations are based on making no releases that contribute to flows exceeding maximum non-damaging flow limits at downstream gages that may be located several days of flow travel time below the dam.

The timing and attenuation of flows or flow changes cascading downstream through a river/reservoir system is reflected in flow forecasting and flow routing. These effects are typically not explicitly addressed in modeling with a monthly computational time step but may be quite significant with smaller time steps. Pertinent effects of stream flow depletions and inflows propagating through a river/reservoir system typically occur over time scales of less than a month. Translating effects of actions occurring late in one month to the early part of the next month is not possible if the model is based on lumped monthly volumes. The WRAP simulation program *SIM* has no explicit features for either forecasting future stream flows or modeling timing (lag) and attenuation effects because it is limited to a monthly time step. *SIMD* provides optional capabilities for stream flow routing and forecasting for use with sub-monthly time steps.

In *SIM* or *SIMD*, a water rights priority loop is nested within a period loop. The simulation progresses sequentially through time. In each time step, computations are performed for each water right (set of water control and use requirements) in priority order. As each set of requirements is considered, the following tasks are accomplished within *SIM* and in an expanded form reflecting forecasting and routing in *SIMD*. Flow forecasting in *SIMD* is performed in conjunction with the first task. Routing is performed in conjunction with the 1st and 4th task.

1. The amount of water available to that water right is determined as the minimum of available stream flows at the control point of the water right and at control points located downstream. In the *SIMD* simulation of flood control operations, the amount of channel flood flow capacity below maximum allowable (non-damaging) limits is determined at all pertinent control points.
2. The water supply diversion target, hydroelectric power generation target, minimum instream flow limit, or non-damaging flood flow limit is set.
3. Decisions regarding reservoir storage and releases, water supply diversions, and other water management/use actions are made; net evaporation volumes are determined; and water balance accounting computations are performed.
4. The stream flow array used to determine water availability and remaining flood control channel capacity at all downstream control points is adjusted for the effects of the water management actions.

Water control and use actions today both affect and are affected by future river flows. Forecasting addresses the issue of considering future flow conditions in current operating decisions. Task 1 listed above consists of determining the amount of water that is available to a water right. Water availability in *SIM* and *SIMD* is based on not allowing a water right to adversely affect the amount of water available to senior rights. This task requires consideration of water availability at control points located downstream. Likewise, *SIMD* flood control operating decisions may affect flows at downstream locations one or more days into the future. In the monthly time step *SIM*, the water availability determination considers only the current month. Flow forecasting capabilities of *SIMD* allow the computational algorithms to look a specified number of days, called the forecast period, into the future in determining water availability and/or remaining flood flow capacities. The flow forecasting feature is based on performing the simulation twice at each time step to allow a look forward at future stream flow conditions prior to making diversion and reservoir operation decisions.

Routing is performed in conjunction with task 4 outlined above where the flows at downstream control points are adjusted for diversions, return flows, and reservoir releases and refilling occurring upstream. Reverse routing occurs in task 1. Changes to flow may also involve reservoir releases made for downstream uses. Meeting water right requirements today may affect flows at downstream locations from one to many days into the future. The effects of a stream flow depletion or return flow addition at an upstream location may require several days, perhaps a week or two, to propagate to the basin outlet. Flow travel times for extremely large river systems may many days. However, for most river systems, flow times will typically be less than a month. Flow routing is typically not feasible with a monthly time step. Routing techniques are incorporated in *SIMD* for routing daily flow changes.

Computer Programs, Data Files, and Input Records

The WRAP programs *SIMD*, *TABLES*, *DAY*, and *DAYH* provide capabilities for modeling based on a daily computational time step. Input and output files are listed in Table 1.2. Input records for *SIMD* and *TABLES* are explained in the *Users Manual*. *DAY* and *DAYH* are described Appendices A and B of this *Daily Manual*. Time series of *SIM* and *SIMD* hydrology input data can be input either in a hydrology DSS file or in the DIF, FLO, EVA, and other input files. *SIM/SIMD* simulation results can also be recorded alternatively in a DSS file or in OUT and SUB files. The use of DSS input and output files is outlined in Chapter 6 of the *Users Manual*.

Daily Simulation Model SIMD

All *SIM* simulation algorithms and input file structures were preserved while adding sub-monthly time step features to create *SIMD*. All features of *SIM* are also included in *SIMD*. The following additional record types provide input for the *SIMD* daily time step features. The *JT* record is the only record required to activate daily features. The other records are optional, providing information that may be needed for various features. Descriptions of these *SIMD* input records are provided in Chapter 4 of the *Users Manual*.

DAT File Input Records

- *JT* and *JU* records control time step, output, and forecasting options.
- *FR*, *FF*, *FV*, and *FQ* records implement flood control features described in Chapter 5.
- *PF* and *PO* records specify water right targets based on high flow pulses (Chapter 6).
- *DF* records list control point identifiers for daily flow *DF* records in the DSS file.

Records Stored Optionally in Either the DAT and/or DIF Files

- *DW* and *DO* records specify target and forecast options for individual water rights.

DIF File Input Records

- *SC* records provide selection criteria for assigning *DW* and *DO* record parameters.
- *RT* and *DC* records provide routing and flow disaggregation specifications and data.

Records Stored in Either the DSS File (Recommended) or the DIF File

- *DF* records consist of sequences of daily flows or daily flow patterns.

SIMD writes simulation results at daily (sub-monthly) time intervals to a file with the filename extension SUB. The sub-monthly interval simulation results are aggregated by month within *SIMD* to create an output file with the filename extension OUT. The flood frequency analysis file with the filename extension AFF contains annual series of maximum naturalized flow, regulated flow, and reservoir storage. *SIMD* optionally writes routing factor arrays, forecast availability periods, disaggregation parameters, and other optional *SIMD* specific information to the message SMM file. *SIMD* can also store its daily simulation results in a DSS file to be accessed with *HEC-DSSVue*. These five output files created by *SIMD* are optional; either or all may be used. *SIMD* and *SIM* both always automatically create the same message MSS file.

The organization of the SUB file is outlined in Table 2.1. The number of control points, water rights, and reservoirs included in the sub-monthly (daily) SUB and monthly OUT output files are controlled similarly. Likewise, the water right, control point, and reservoir/hydropower output records in the *SIMD* SUB file have the same format as in the *SIM* or *SIMD* OUT file. The fifth line of the SUB file contains extra information not found on the monthly OUT file. Because the daily output file can be limited to any sub-range of the simulation period, the beginning year-month and ending year-month pair are stored in the SUB file. These dates are used by *TABLES* to process daily simulation results that need not span whole years. Output for the first year is not required to start with January nor the final year to end with December.

Table 2.1
Organization of the *SIMD* Daily Output SUB File

First Six Records of *SIMD* SUB Output File

WRAP-SIMD (May 2019 Version) Output File

TITLE1

TITLE2

TITLE3

BEGYR BEGMON ENDYR ENDMON DAYS NCPO2 NWROUT2 NREOUT2

NTI NDAY(1,...,12)

Definition of Variables on Fifth Record

BEGYR – first year in output file

BEGMON – first month in output file

ENDYR – last year in output file

ENDMON – last month in output file

DAYS – number of days (time steps) in output file

NCPO2 – number of control points in output file

NWROUT2 – number of water rights in output file

NREOUT2 – number of reservoirs in output file

Definition of Variables on Sixth Record

NTI – parameter (*JT* record) indicating calendar or user defined intervals in each month

NDAY(1,...,12) – number of time intervals used per month

Block of Records Repeated for Each Period (Month)

water rights output records (number of records = *NWROUT2*)

control point output records (number of records = *NCPO2*)

reservoir/hydropower output records (number of records = *NREOUT2*)

Total Number of Records in SUB File for Calendar Day Simulations

number of records = $6 + (12 \times NYRS \times \sum NDAY + (\text{Number of Leap Years})) \times (NWROUT2 + NCPO2 + NREOUT2)$

Total Number of Records in SUB File for User-Defined *NDAY* Simulations

number of records = $6 + (12 \times NYRS \times \sum NDAY) \times (NWROUT2 + NCPO2 + NREOUT2)$

The OUT file developed by *SIMD* is indistinguishable in format from an OUT created by *SIM*. The user selects which water right, control point, and reservoir/hydropower records to write to the *SIMD* OUT file using the *JD* input record in the same manner as for a *SIM* simulation. The OUT file covers the entire simulation period.

The SUB file generated by *SIMD* contains water right, control point, and reservoir/hydropower records with the sub-monthly time step simulation results. These daily simulation results are also aggregated to form the monthly OUT file. The data selected for output to the SUB file are selected on the *JT* record in the DAT file independently from the data selected for the OUT file on the *JD* record. Thus, the model-user is able to obtain basin-wide output at the monthly time scale, while separately obtaining data for a select few locations at the daily time scale. Another output management option for the SUB file is selection of a sub-range from the entire simulation period-of-analysis. The user can select a starting month-year and ending month-year combination from within the entire simulation period. The selected sub-period does not have to begin and end with whole years. This option will not affect the full period-of-record simulation reporting that is sent to the monthly OUT file. These features are designed to provide flexibility for the user to limit the potentially huge size of the daily SUB file.

The sixth line of the SUB file contains information describing the number of time steps in each of the 12 months. The first entry is the parameter *NTI* from the *SIMD* input file *JT* record that flags the pattern of periods per month in array *NDAYS* as either user defined or the default calendar days. If *NTI* indicates that the array *NDAYS* follows a daily pattern, *TABLES* determines which years are leap years and assigns the value 29 for February in the array *NDAYS*.

Flood control reservoir operation features are described in Chapter 5. *SIMD* generates an annual flood frequency file with the filename extension *AFF* that contains the maximum daily naturalized flow, regulated flow, and reservoir storage volume for each year of the simulation. The *TABLES 7FFA* record activates a routine in *TABLES* that performs flood frequency analyses using the data in the *SIMD* output *AFF* file.

Program *SIM* will read a *SIMD* daily input dataset, ignoring the *SIMD* input records that are not relevant to *SIM*, and perform a monthly simulation. *SIMD* cannot ignore *SIMD* input records. However, *SIMD* will read a monthly *SIM* input dataset and perform a monthly simulation, with the same monthly results as *SIM*.

Post-Simulation Program TABLES

The monthly simulation results recorded in a *SIMD* OUT file have the same format as the results stored in a *SIM* OUT file. Program *TABLES* processes an OUT file from *SIMD* exactly the same as an OUT file from *SIM*. The SUB output file generated by *SIMD* containing sub-monthly time interval simulation results is also processed in essentially the same way by *TABLES*. The same *TABLES* TIN input file used for OUT file processing can be used for SUB file processing with minimal modification.

The WRAP program *TABLES* is described in Chapter 5 of the *User's Manual* and Chapter 7 of the *Reference Manual*. The following *TABLES* type 6 records are designed specifically for organizing the *SIMD* SUB file simulation results as explained in the *Users Manual*.

- Daily time series records such as 6NAT, 6REG, 6UNA, 6STO, 6DIV are analogous to the monthly time series records 2NAT, 2REG, 2UNA, 2STO, 2DIV.
- 6REL and 6RET reliability analysis records are daily versions of the monthly 2REL and 2RET records.
- 6FRE and 6FRQ frequency analysis records correspond to 2FRE and 2FRQ records.
- The 6RES reservoir storage reliability and drawdown frequency record is the daily version of the monthly 2RES record.

The *TABLES* type 7 records described in Chapter 5 of the *Users Manual* deal with flood frequency and damage analyses. The 7FFA record controls flood frequency analyses of peak annual series of storage, naturalized flow, and regulated flow from a *SIMD* AFF file, which are described in Chapter 7 of the *Reference Manual* along with other frequency analysis methods. An 7FFA flood frequency analysis example is presented in Chapter 9 of this *Daily Manual*.

Programs for Developing *SIMD* Daily Stream Flow Input

Development of daily stream flow datasets is one of several WRAP applications of *HEC-DSSVue* as described in Chapter 6 of the *Users Manual*. Observed and computed daily stream flows are analyzed, manipulated, and managed within *HEC-DSSVue*.

The two programs described in Appendices A and B of this *Daily Manual* provide sets of optional routines for developing *SIMD* input data that include calibrated values for routing parameters and daily flow pattern hydrographs for use within *SIMD* in disaggregating monthly naturalized flows to daily. Programs *DAYH* (Appendix B) and *DAY* (Appendix B) were developed during 2005-2010 and 2016-2017, respectively. Calibration of routing parameters is a key primary purpose of both programs. The calibration routine in the old *DAYH* (original *DAY*) is based on applying a genetic optimization algorithm to entire upstream and downstream hydrographs. The calibration routine in the new *DAY* is based on statistical analyses of upstream and downstream changes in stream flow. The alternative *DAY* and *DAYH* routing parameter calibration procedures are explained in Chapter 4. These and other capabilities along with differences and similarities between the two programs are described in Appendices A and B.

Monthly-to-Daily Disaggregation

The daily *SIMD* simulation model is an expanded version of the monthly *SIM*. The computational algorithms of both *SIM* and *SIMD* are organized based on stepping through the hydrologic period-of-analysis month-by-month. The daily simulation divides each month into daily time intervals, thus increasing the number of computational time steps. Each month except February having either 31 or 30 days. February has 28 days except for leap years with 29 days.

The simulation computations are performed for each time step of the hydrologic period-of-analysis. Selected *SIMD* daily simulation results may be written to the DSS and SUB output files for each time step as specified by output control parameters included on the *JD*, *WO*, *CO*, *GO*, *RO*, and *OF* records in the DAT input file. *SIMD* also totals the daily simulation results to aggregated monthly amounts which are recorded in the DSS and OUT files. The routines in

TABLES handle the daily (sub-monthly) simulation results in a *SIMD* SUB output file or the monthly results in a *SIM* or *SIMD* OUT file in the same manner. Both daily and monthly simulation results are recorded as DSS records in a single DSS output file and managed in the same manner.

The process of subdividing monthly quantities into daily amounts is referred to as disaggregation. The opposite process of summing daily values to monthly totals is called aggregation. Monthly values of input variables are disaggregated within *SIMD* to daily amounts as follows.

- *Naturalized flows* may be provided directly as input data on *DF* records at a daily interval. Alternatively, daily naturalized flows may be computed within the *SIMD* simulation by disaggregating monthly flows using the alternative options described later in this chapter. Monthly flow adjustments from *FA* records in a FAD or DSS file are added to the naturalized flows prior to the disaggregation.
- *Instream flow targets* may be uniformly distributed over the days of each month. Alternatively, other options described later in this chapter may be adopted.
- *Diversion and hydropower targets* may be uniformly distributed over the days of each month. Alternatively, options allow targets to vary non-uniformly during a month depending upon daily water availability and various other considerations.
- *Net evaporation-precipitation depths* from the *EV* records in a DSS or EVA file and *constant inflows* from *CI* records in a DAT file are uniformly disaggregated. The monthly quantities are simply divided by the number of days in the month.

Disaggregation of Naturalized Stream Flows

The Texas WAM System contains datasets of monthly naturalized flows. Disaggregation options are adopted when applying daily time steps. In applying WRAP outside of Texas, the optimal daily time step modeling strategy will also often be to develop monthly naturalized flow sequences for use in combination with the *SIMD* disaggregation methods. Selecting and applying flow naturalization and disaggregation strategies is a somewhat subjective process of making optimal use of available monthly and daily flow data. Historical gaged daily flow records and daily data related to past water control and use required to convert gaged flows to naturalized or unregulated flows may be limited in availability. Lag and attenuation effects complicate the process of naturalizing gaged flows and transferring them to ungaged sites. Converting gaged daily flows to naturalized daily flows at pertinent locations may be difficult for extensively developed river basins. Observed flows recorded at gages may be adopted without modification for use as disaggregation daily pattern hydrographs in many cases.

SIMD reads monthly flow volumes for primary (gaged) control points from *IN* records stored in a FLO or DSS file and distributes the flows to secondary (ungaged) control points using DIS file parameters just like *SIM*. These monthly flows are then disaggregated to daily amounts within the *SIMD* computational routines. The alternative disaggregation methods all convert sequences of monthly naturalized flow volumes into daily flow volumes that preserve the monthly amounts. The sum of disaggregated daily volumes equals the monthly volume in each month.

Flow Disaggregation Methods

The alternative *SIMD* methods outlined in Table 2.2 for dividing monthly naturalized flow volumes between time steps within each month are activated with the *JU* and *DC* records. The parameter *DFMETH* in *JU* record field 2 sets a global default option. The default for this default setting option is *DFMETH* option 4 defined in Table 2.2. The global default defined by the *JU* record is applied to all control points unless overridden for individual control points by *DFMETHOD(cp)* on *DC* records. Different methods may be adopted for different control points.

Table 2.2
Alternative *SIMD* Flow Disaggregation Methods

Daily Flows Input Without Monthly Flows

No Disaggregation – Daily flows are provided on daily flow *DF* records for use directly without disaggregating monthly flows. Monthly flows are not required.

Monthly Flows Disaggregated without Input of Daily Flows

1. *Uniform Distribution Option* – Monthly flow volumes are distributed evenly over the month with the same amount assigned to each daily time step.
2. *Linear Interpolation Option* – A linear spline interpolation routine is applied to the sequence of monthly flow volumes to assign a non-uniform daily flow distribution.

Monthly Flows Disaggregated Using Input Daily Flow Pattern Hydrographs

3. *Variability Adjustment Option* – The daily flow volumes computed with the linear interpolation routine (option 2 above) are adjusted to reflect the variability determined from daily flow sequences provided as input on daily flow *DF* records.
4. *Flow Pattern Option* – Daily flow amounts on *DF* records in a *DSS* or *DIF* file define a daily flow distribution pattern. Monthly volumes are disaggregated to daily in proportion to daily pattern flow hydrographs while maintaining monthly totals. This option is the standard recommended method for most applications.

Adjustments in Transferring Flow Patterns to Other Control Points

5. *Drainage Area Ratio Transfer Option* – The daily flow pattern defined by the *DF* record flows are adjusted for location upstream or downstream with a nonlinear equation that is based on a drainage area ratio.
6. *Regression Equation Transfer Option* – The daily flow pattern defined by the *DF* record flows are adjusted for location upstream or downstream with a nonlinear equation that is based on regression coefficients.

DFMETHOD(cp) and the other parameters entered on the *DC* record for a particular control point can be automatically repeated for any number of upstream control points by activating the parameter *REPEAT* on the *DC* record. All control points located upstream of the

control point listed in *DC* record field 2 will be assigned the same disaggregation option and parameters from the *DC* record. Previously set values of the disaggregation option and other *DC* record parameters are overwritten as each *DC* record is read and processed from the DIF file.

The *uniform distribution* (option 1) and *linear interpolation* (option 2) methods require no additional data not already found in a monthly *SIM* simulation dataset. Options 1 and 2 may be adopted for use with existing WAM System datasets without additional input data requirements. However, these methods smooth out the extreme variability typically exhibited by actual flows.

Options 3 and 4 in Table 2.2 are based on reproducing the daily variability characteristics of available daily flow sequences. The *variability adjustment method* (option 3) is based on adjusting the flows computed by linear interpolation (option 2) to reflect greater more realistic variability. The *flow pattern method* (option 4) uses flows provided on *DF* records to establish a daily flow pattern. The daily flow sequences provided on *DF* records are used by *SIMD* in options 3 and 4 to set the pattern of variability and may be input for all or portions of the hydrologic period-of-analysis at any number of locations. The variability pattern derived from one or several years of daily flows may be repeated multiple times in disaggregating monthly flows covering a much longer simulation period-of-analysis. *DF* records developed for a particular location may be used to disaggregate monthly flow sequences to daily time steps at many different control points.

Option 4 is the recommended standard flow disaggregation method expected to be most often employed. All of the options listed in Table 2.2 are described in the following paragraphs.

Option 1 – Uniform Distribution

The uniform distribution option consists of computing daily flow volumes by simply dividing the monthly flow volume by the number of days (28, 29, 30, or 31) in the month.

Option 2 – Linear Interpolation

Linear spline interpolation may be applied to a sequence of monthly naturalized flows to obtain non-uniform daily amounts. The methodology is illustrated graphically in Figure 2.2. Instantaneous flows at the beginning, middle, and end of each month are defined based on the flow volumes in the preceding, current, and subsequent months. The straight lines connecting these points are called linear splines. The splines represent instantaneous flow rates at points in time, and the areas under the splines represent flow volumes during intervals of time. The splines define areas representing monthly flow volumes which are dissected at sub-monthly intervals to disaggregate the monthly volumes into sub-monthly volumes.

The shaded bars in Figure 2.2 represent the monthly naturalized flow volumes that are to be disaggregated. The linear interpolation splines connect the beginning, middle, and ending points of each month. The end of one month is the beginning of the next month. The spline flows at the beginning and end of each month are set as the average of the mean instantaneous flow rates associated with the monthly volumes of adjoining months. Middle-of-month flow points are then set based on conserving the total monthly flow volume. The middle-of-month flow point is selected such that the monthly flow volume being disaggregated is represented by the area under the two linear splines spanning that month.

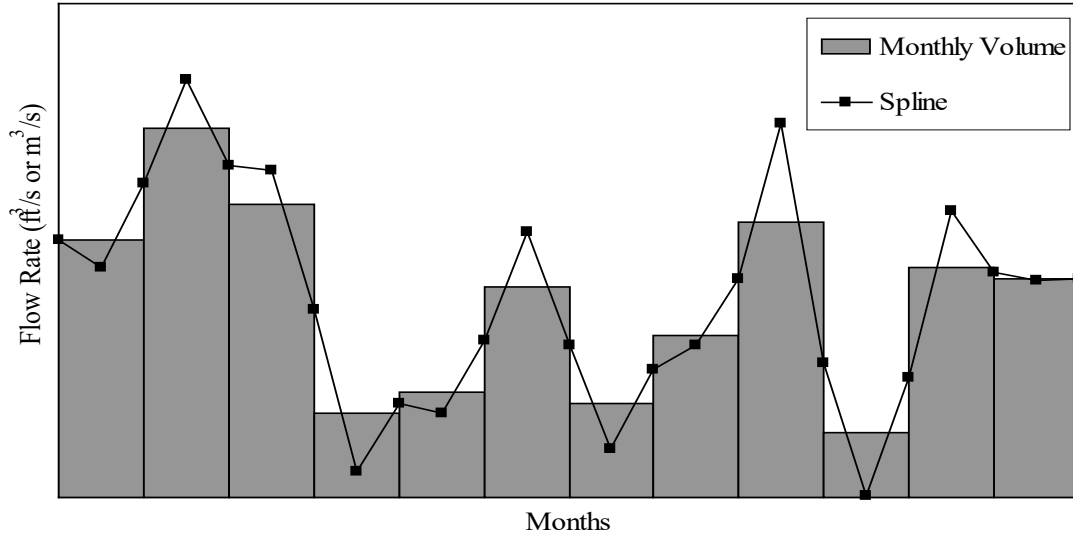


Figure 2.2 Linear Interpolation of Flow Volumes

In some cases, with beginning/end-of-month flow points set as averages of adjacent mean monthly flows, the preservation of the monthly volume by defining a single middle-of-month point may result in negative middle-of-month flow rates. When such a negative flow occurs, two zero-flow points are set within the month defining a period of zero flow during the middle of the month that results in preservation of the total volume for the month without creating negative flows. A zero monthly volume results in a zero instantaneous flow rate for the entire month.

The linear interpolation method for disaggregating monthly flows to daily volumes results in smoother and more serially correlated daily flow sequences than the actual observed daily flows. Thus, the method may be best applied to streams that are base-flow dominated with lesser fluctuations. The linear interpolation method typically works better for normal and low-flow periods of the simulation than for flood flows that exhibit greater fluctuations. Option 3 described next is designed to adjust daily flows resulting from the linear interpolation splines to add greater variability representative of actual daily flows.

Option 3 – Variability Adjustment

The linear interpolation method described in the preceding section requires no input data other than the sequences of monthly naturalized flows but tends to smooth out daily flow variations. Flow variability is modeled more realistically by incorporating information provided by input sequences of daily flows. The variability adjustment option methodology is based on using flow variation patterns from actual daily flows input on *DF* records to adjust the daily flows computed by the linear interpolation procedure. With all of the alternative disaggregation methods, the sum of the disaggregated daily flows is the original monthly amount.

The variability adjustment option is designed for the common situation in which a complete dataset of monthly naturalized flows are combined with limited available sequences of daily flows.

Daily flow sequences for one or a few years at one or a few locations may be used to establish patterns which are then used in disaggregating monthly flows to daily flows for the complete period-of-analysis at all control point locations. Patterns of variability derived from limited sequences of daily flows are repeated for multiple time periods and multiple locations.

The combined linear interpolation with variability adjustment strategy (option 3 in Table 2.2) consists of the tasks outlined in Table 2.3. The methodology is based on a daily pattern ratio (VR) defined as follows.

$$VR = 1.0 \quad \text{if} \quad I_{DF} \leq (VRL)DF \quad (2.1)$$

$$\text{Otherwise} \quad VR = \frac{DF}{I_{DF}} \quad (2.2)$$

The VR is computed for each day from daily flows (DF) provided on *DF* records and interpolated flows (I_{DF}) computed from the corresponding aggregated monthly volumes. If I_{DF} is zero or extremely small relative to DF, the methodology is not valid and thus the ratio VR is set at 1.0 meaning the variation between I_{DF} and DF is not considered.

Table 2.3
Combined Linear Interpolation with Variability Adjustment Strategy

-
1. A sequence of variability ratios (VR) used to increase the variability of daily flows (I_Q) computed by interpolating monthly volumes (Q_M) is developed from daily flows (DF) read from *DF* records. The procedure includes the following tasks.
 - The daily flow (DF) sequence is converted to a monthly sequence. Daily flow volumes are summed for each month to obtain monthly flow volumes.
 - The aggregated monthly flow volumes are disaggregated to daily flows (I_{DF}) using the linear interpolation methodology outlined in the preceding section.
 - The ratio (VR) of *DF* record flows (DF) to interpolated flows (I_{DF}) is computed for each day.
 2. The *SIMD* monthly flows (Q_M) are disaggregated to daily flows (I_Q) using the linear interpolation methodology outlined in the preceding section.
 3. For each month, the sequence of daily variation ratios (VR) developed in task 1 are combined with the interpolated daily flows (I_Q) developed in task 2 to obtain first the daily pattern flows (P_D) and then the daily flows (Q_D) used in the simulation.
 - The sequence of daily deviation factors (VR) from task 1 is multiplied by the interpolated daily flow volumes (I_D) associated with the *SIMD* monthly flows (Q_M) for that particular month and location to obtain daily flows (P_D) defining a pattern of variability. Monthly totals (P_M) of P_D are computed.
 - The daily pattern flows (P_D) are scaled (Q_M/P_M) to obtain the sequence of naturalized flow volumes (Q_D) for each day of each month at that location which is adopted for the *SIMD* simulation.
-

The I_{DF} for each day is computed by applying linear interpolation to the aggregated monthly sums of the daily flows (DF) read from the *DF* records. The sequence of daily variability ratios (VR) represents the pattern of variability in daily flows expressed as a ratio of the actual daily flow volume (DF) read from *DF* records to the daily flow volume (I_{DF}) computed by the linear interpolation methodology. The Eq. 2.2 ratio is undefined for an I_{DF} of zero, and VR may be unrealistically large for extremely small I_{DF} . Thus, VR is set at 1.0 if I_{DF} is either zero or very small relative to DF as defined by the limit VRL in the conditional statement of Eq. 2.1. By default, VRL is set at 0.10 unless otherwise specified on the *JU* record. VR is zero for each day that has zero flow on the *DF* record. Thus, the method reproduces the same percentage of days with zero flow for the daily flows (Q_D) adopted for the *SIMD* simulation as is found on the *DF* records.

The linear interpolation methodology is applied to the *SIMD* monthly flow volumes (Q_M) to compute daily flows (I_Q). Equation 2.3 combines the interpolated flows (I_Q) with the daily flow variability ratios (VR) computed with Eqs. 2.1-2.2 to develop a sequence of flows (P_D) defining a flow pattern. The daily pattern flow volumes (P_D) are aggregated to monthly volumes P_M with Eq. 2.4. The daily flows (Q_D) adopted for the simulation are computed with Eq. 2.5.

$$P_D = I_Q(VR) \quad (2.3)$$

$$P_M = \sum P_D \quad (2.4)$$

$$Q_D = \left(\frac{Q_M}{P_M} \right) P_D \quad (2.5)$$

The disaggregated daily flows (Q_D) used in *SIMD* sum to the monthly *SIMD* volumes (Q_M) and have the same pattern of variability as the pattern flows (P_D).

Option 4 – Replication of Daily Flow Patterns while Preserving Monthly Volumes

A sequence of daily flow volumes defining a pattern of variability may be input to *SIMD* on *DF* records in a DSS or DIF file. (The DSS file is the standard recommended file option.) The same flow pattern may be automatically repeated within *SIMD* for any number of control points.

A monthly naturalized flow volume (Q_M) is disaggregated into daily flows (Q_D) within *SIMD* using a sequence of daily pattern flows (P_D) read as input based on Eq. 2.5. Each monthly volume (Q_M) is proportioned to daily volumes (Q_D) in the same ratio as the daily pattern flows (P_D) divided by their monthly total (P_M).

$$Q_D = \left(\frac{Q_M}{P_M} \right) P_D \quad (2.5)$$

Option 4 is the default recommended standard method for disaggregating monthly naturalized flows to daily in *SIMD*. An option 4 flow pattern defined by a set of *DF* records may be applied to multiple locations with or without applying options 5 and 6 described on the next page. Most applications are expected to adopt option 4 for essentially all sites with pattern hydrographs at gaged sites being applied at multiply ungaged sites without using the option 5 and 6 transfer method adjustments.

Options 5 and 6 – Optional Methods for Transferring a Daily Pattern to Other Locations

The flow pattern method option 4 is based on entering a sequence of daily flows that are representative of flow variability. The pattern of daily flows derived from gaged flows at one particular location may not necessarily be representative of flows at various other sites with smaller or larger or otherwise different watersheds. Options 5 and 6 are methods for applying adjustments in transferring the flow pattern represented by *DF* record flows to other locations. Judgement is required in determining whether these adjustments are worthwhile in various circumstances. A flow pattern hydrograph may be applied at multiple sites either with or without adjustment.

A lag option activated by the parameter *LAG* entered on the *DC* record allows the daily flows to be shifted forward or backward in time for control points located upstream or downstream. The flows are simply translated a specified number of days to reflect timing. The options 5 and 6 transfer methods change the relative magnitude of the flows to reflect watershed runoff differences between different control point locations.

Monthly naturalized flows are distributed from locations of gaged or known flows to ungaged control points in the same way in either *SIMD* or *SIM* using the same computational methods outlined in the *Reference* and *Users Manuals* with watershed parameter input data from a *DIS* file. Monthly flows at ungaged (unknown flow) control points are computed based on monthly flows at gaged (known flow) control points and watershed parameters. Monthly naturalized flow volumes at all control points are then disaggregated into daily amounts.

Daily flow variability patterns as well as total monthly volumes may vary with location. For example, daily flows at an ungaged upstream site with a relatively small watershed may exhibit greater variability than daily flows at a gaging station located downstream that has a much larger watershed. The flows provided on *DF* records are typically from a gaging station. The pattern of daily fluctuations derived from these flows may be applied to disaggregate monthly flows at other ungaged control point locations. Options 5 and 6 listed in Table 2.2 are techniques for adjusting the daily flow pattern established with option 4 to reflect other locations in the river system with different watershed characteristics. Option 4 may be applied either with or without options 5 or 6 depending on whether the adjustment of flow variability patterns for watershed differences is considered significant and/or feasible. Options 5 and 6 are based on Equations 2.6 and 2.7, respectively. A related option activated by *LAG* on the *DC* record allows the entire period-of-analysis daily flow pattern sequence to be lagged backward or forward in time any number of days to account for the routing lag between locations.

The option 5 transformation of the option 4 flow pattern from a source location to a destination location is based on a drainage area ratio and empirically determined exponent *X*.

$$P_{\text{destination}} = \left[P_{\text{source}} \left(\frac{DA_{\text{destination}}}{DA_{\text{source}}} \right) \right]^X \quad (2.6)$$

P denotes the daily flows defining the flow pattern, and *DA* denotes drainage areas from the *DIS* file. The exponent *X* will typically be greater than 1.0 when transferring a pattern from a downstream source control point to an upstream destination control point. Conversely, *X* will typically be less than 1.0 in transforming a flow pattern from upstream to downstream.

Option 6 is an alternative to option 5 for transferring an option 4 flow pattern from a source location to a destination location with different watershed characteristics. The flow pattern adjustment is based on the following non-linear regression equation with empirically determined regression parameters A, M, and X.

$$P_{\text{destination}} = A + M (P_{\text{source}})^X \quad (2.7)$$

The feasibility of applying Equations 2.6 or 2.7 to adjust variability patterns to reflect watershed differences is dependent upon the availability of daily flow data from either gage observations or watershed precipitation-runoff models with which to establish the coefficients A, M, and X. Investigation of parameter estimation procedures is a subject for further research.

Naturalized flow volumes for daily time intervals, in acre-feet/day or other units, may be input directly on *DF* records. If daily flows are provided on *DF* records for all primary (gaged) control points, the flow distribution options can be applied to transfer the daily flows to secondary (ungaged) control points using parameters from a DIS file in the same manner as monthly flows are distributed from gaged to ungaged locations. However, if monthly flow disaggregation at some control points is combined with reading daily flows directly from *DF* records at other control points, the flow distribution options associated with DIS file parameters are applied only to the monthly flows. However, the daily flows may be transferred to other locations with disaggregation options 5 and 6 defined in Table 2.2 and discussed later in this chapter.

Daily Flows in SIMD Input Datasets

Daily flows of rivers in Texas and elsewhere are characterized by extreme variability. The daily flow pattern option (option 4 in Table 2.2) is the standard monthly-to-daily flow disaggregation method adopted for daily WAMs in Texas to properly simulate the great variability exhibited by stream flow throughout the state. This option requires daily flow pattern hydrographs that represent naturalized flow conditions reasonably accurately.

Daily naturalized flows input on *DF* records can be used directly in a daily *SIMD* simulation without monthly naturalized flows. However, disaggregation method 4 provides the significant advantage of allowing the monthly naturalized flow volumes to be maintained while replicating the patterns reflected in the daily flow hydrographs. Variability characteristics are replicated from the daily pattern flow sequences while preserving the monthly flow volumes.

Daily flow *DF* records may contain either daily naturalized flow volumes, typically in units of acre-feet, or other quantities that represent flow patterns such as mean daily flows in cubic feet per second (cfs) as recorded for U.S. Geological Survey (USGS) gaging stations. In employing daily flow quantities to define patterns, only the relative amounts affect the computation results.

Monthly-to-daily disaggregation is performed within *SIMD* as an integral part of the simulation. Naturalized flow disaggregation computations are also included in the utility programs *DAY* and *DAYH*. Sequences of river flows or flow patterns may be developed with *DAY* or *DAYH* for input to *SIMD*. Although flow pattern hydrographs are not required to be actual daily volumes summing to the monthly totals, naturalized monthly flows disaggregated to daily flows, and thus summing to the correct monthly volumes, may be adopted for the *SIMD* input pattern hydrographs.

Automated Procedure for Repeating Daily Flows at Multiple Control Points

Sequences of daily flows are input to *SIMD* as *DF* records at selected control points, which are typically the sites of stream gaging stations. The *DF* record flows input for a particular control point may also be employed at any number of other control points. The *SIMD* computational procedure outlined below automatically assigns daily flows to all control points by repeating the *DF* record flows inputted for selected control points. The resulting assignments and related information can be viewed in message SMM file tables. *JU*, *DC*, and *DF* record parameters provide flexibility for modifying the standard automated assignments.

Each *DF* record daily flow hydrograph is identified by a control point identifier entered on the *DF* records. If a control point has *DF* records included in the DSS or DIF file, those daily flows are assigned to the control point. Otherwise, if there are no *DF* records containing a particular control point identifier, daily flows are assigned to that control point based on the following criteria, which are listed in priority order.

1. Daily flows are assigned to the non-*DF* record control point by repeating flows from the nearest *DF* record control point located downstream of the non-*DF* record control point.
2. If no *DF* record control point is found downstream of the non-*DF* record control point, the assignment procedure then looks upstream. Flows at the nearest upstream *DF* record control point are adopted, where "nearest" is defined in terms of number of intervening control points.
3. With no *DF* record control points located either downstream or upstream of the non-*DF* record control point, a *DF* record control point on another stream that confluences with the stream of the non-*DF* record control point is selected based on minimizing the number of control points between the non-*DF* record control point and adopted *DF* record control point.

DSS and DIF File Strategies for Managing DF Record Daily Flow Sequences

Daily flows are input to *SIMD* as *DF* records in the form of either binary DSS records in a DSS file (recommended option) or as text records in a DIF file. The daily flows are much more efficiently compiled and managed within DSS. The term "*DF* record flows" is used in this manual to refer to daily flows from a *SIMD* input dataset regardless of whether read from DSS records in a DSS input file or as text records in a DIF input file.

The switch parameter DFFILE in *JU* record field 3 specifies whether *DF* record daily flows are read from a DSS file or DIF file. With the default DFFILE option 1, daily flows are read from the DSS file. Option 2 consists of reading daily flows from the DIF file. With DFFILE option 3, daily flows are read from the DIF file and written to the DSS file. Option 3 allows *DF* record flows originally compiled in DIF file format to be conveniently converted to DSS file records.

SIM/SIMD monthly naturalized flows, net evaporation rates, and other monthly time series input data, and *DF* record daily flows are read from a single hydrology DSS input file with filename rootHYD.DSS as explained in Chapter 6 of the *Users Manual*. The daily input data DIF file contains *RT*, *DE*, *DH*, *DC*, and optionally *DF* and other types of records as explained in Chapter 4 of the *Users Manual*. The DFFILE options control only the handling of the *DF* record

daily files. Other input data contained in the DIF file is applicable regardless of whether the *DF* records are stored in the DIF file or DSS file.

Monthly-to-daily naturalized flow disaggregation methodologies are the same regardless of whether the daily flow pattern hydrographs are input in a DSS or DIF file. The *SIMD* automated algorithm for assigning daily flows input for a particular control point to any number of other control points is also the same regardless of whether the daily flow pattern hydrographs are input in a DSS or DIF file. Other capabilities controlled by *DC* record parameters are also the same, such as over-riding the automatic flow repetition assignments. The DSS file versus DIF file daily flow input strategies (DFFILE options 1 and 2) differ as follows.

- With daily flows read from a DSS file, the DAT file must contain *DF* records listing control point identifiers for each and every control point for which daily flows are read from the DSS file. With daily flows read from the DIF file, *DC* records or any other records listing all of the control points that have *DF* record daily flows are not required.
- Daily flows from the DIF file may optionally cover only the portion of the hydrologic period-of-analysis specified on *DC* records. Flows are automatically synthesized within *SIMD* for the sub-periods of missing flows by repetition of the DIF file *DF* record daily flows. Daily flows in the DSS file must cover the entire hydrologic period-of-analysis. However, time series data in the DSS file can be conveniently manipulated within *HEC-DSSVue*.

Diversion, Hydropower, and Instream Flow Targets

Targets for water supply diversions, hydroelectric power generation, and instream flow requirements are set in a *SIMD* daily simulation by combining selected options from the following four sets of target-building options.

1. A monthly target is determined at the beginning of each month in a *SIMD* daily simulation in the same manner as a *SIM* or *SIMD* monthly simulation. *UC* record use coefficients are combined with an annual target from a water right *WR* or instream flow *IF* record. The target may be adjusted further by target options *TO*, supplemental options *SO*, cumulative volume *CV*, flow switch *FS*, drought index *DI*, and other supporting records.
2. The monthly target set in step 1 above is distributed over the days of the month using one of the following two alternative approaches as specified by parameters on *JU* and *DW* records.
 - uniform distribution
 - specified number of days (*ND*) option employed with or without the shortage recovery (*SHORT*) option
3. The daily target for a *WR* or *IF* record water right optionally may be set or adjusted using options specified on *DW* and *DO* records that are analogous to the *TO*, *SO*, *BU*, *CV*, *FS*, and *DI* record monthly target setting options noted in step 1 above.
4. Environmental flow standards can be modeled with *IF*, *HC*, *ES*, *PF*, and *PO* records as described in Chapter 4 of the *Reference Manual*, Chapters 3 and 4 of the *Users Manual*, and Chapters 6 and 8 of this *Daily Manual*.

Uniform Distribution and ND/SHORT Options

The monthly target is set at the beginning of the month as specified by a *WR* or *IF* record and accompanying *UC*, *TO*, *SO*, *CV*, *FS*, *DI*, *TS*, and other optional auxiliary records. The monthly target is distributed over the days of the month based on either a uniform distribution or the features controlled by the *ND* and *SHORT* parameters as follows.

A global default daily target distribution option may be set on the *JU* record. This default can be overridden for individual water rights by options activated by the daily water right data *DW* record associated with each individual water right. The *JU* and *DW* record default for the conversion of monthly to daily targets is the uniform distribution option described as follows.

Monthly targets may be evenly divided into daily amounts. A monthly target is divided by the number of sub-intervals in each month to obtain amounts for each computational time step. With this option, a shortage occurs any time a daily target is not fully met.

Options activated by the parameters *ND* and *SHORT* entered on the *JU* or *DW* record provide an alternative to the uniform distribution that may be applied to diversion, hydropower, or instream flow targets. The *ND* option allocates the monthly target to a specified *ND* number of days each month. The daily target amount during the *ND* days is the monthly target divided by *ND*. The period of *ND* days always begins in the first day of the month. The *ND* option may be combined with the *SHORT* option to recover shortages in subsequent days of the same month.

The parameter *SHORT* on the *JU* or *DW* record is a switch that activates an option used in combination with the *ND* option that allows shortages to be supplied later in the same month. With the *ND* option, if the target is fully met during each of the first *ND* days of the month, the target is zero for the remainder of the month with or without the *SHORT* option. However, with the *SHORT* option, a failure to meet the full target amount during the first *ND* days results in an attempt to recover shortages in subsequent days of the month if sufficient water is available.

As an example of the *ND* daily target distribution option, agricultural irrigation practices might involve three 2-day irrigations during each of several selected months of the year. The entire monthly diversion occurs in just 6 days. A *ND* of 6 days sets the target at 1/6 of the monthly target in each of the first six days of the month. If this target is fully met, the target is zero for the remaining days of that month. With the *SHORT* option activated, shortages during the first 6 days and subsequent days are accumulated and treated as a daily target of up to 1/6 of the monthly target in the seventh and subsequent days of that month. The daily target is limited to not exceed 1/6 of the monthly target regardless of cumulative shortage amount to be made up from preceding days.

As another example, assume two days is entered for the parameter *ND* on the *DW* record associated with a particular water right *WR* record. Diversions in any day are limited to a maximum of 1/2 of the monthly target. Half of the entire monthly target is met in each of the first two days of the month if sufficient water is available. An attempt in day three is made to recover any shortage in meeting the target in days one and two. Recovery of any remaining shortage is attempted in day four and so forth throughout the remainder of the month. A municipal or industrial water supply system with storage tanks providing storage capacity to deal with fluctuations in daily supply and demand may be modeled in this manner.

As a final example, assume a requirement for a monthly volume of inflow to an estuary is modeled with an *IF* record in a daily simulation. Conditioning the *IF* record with an ND of 1 day and enabling SHORT allows the monthly instream flow requirement to be met in the first day or as early as possible each month. After the monthly instream flow volume requirement is supplied, the *IF* record instream flow requirement no longer constrains water availability for other water rights during the remaining days of that month.

Sequential Step-by-Step Monthly and Daily Target-Building Process

Distribution of a monthly target to daily amounts may be performed solely by the *JU* and *DW* record options described above. Optionally, further adjustments may be applied as follows as specified by parameters on the *DW* and *DO* records.

The *Reference* and *Users Manuals* describe the step-by-step procedure applied by *SIM* in setting monthly targets. The monthly *SIM* target-setting features are also applied to set monthly targets in a *SIMD* daily simulation. *SIMD* also contains additional daily target-setting options that are analogous to the monthly target setting features. The step-by-step procedure followed in setting monthly and daily targets is outlined as follows. In a daily simulation, *SIMD* first performs steps 1 through 12 to set the monthly target in the same manner as a *SIM* monthly simulation and then performs steps 13 through 21 to convert the monthly target to a daily target.

The following sequential steps are applied in building the monthly target, distributing the monthly target into daily amounts, and finally setting or adjusting the daily target amounts. Steps 1–12 comprise the basic target building procedure outlined in the *Reference* and *Users Manuals*. Steps 13–21 are applied in a *SIMD* daily simulation to create the daily diversion, hydropower, or instream flow targets. In many daily simulation applications, only steps 1, 13, and 21 will be applied for most water rights, with the other optional steps being skipped.

Steps in Building a Monthly Target on the First Day of Each Month

1. Annual targets entered in *WR* or *IF* record field 3 are distributed into monthly amounts using multipliers developed from *UC* records. *UC* records are not required if the target is constant over the year. Alternatively, the *XMONTH* option on the *WR* or *IF* record sets the value in *WR/IF* field 3 as the target in each month. The *DW* record *XDAY* option moves consideration of the *WR* and *IF* record target to step 14 of the target building process. An entry of -9 in *IF* record field 3 activates an alternative option for modeling environmental instream flow standards described in Chapters 6 and 8 that employs *IF*, *HC*, *ES*, *PF*, and *PO* records.
2. The *BU* record activates the backup option as the second step in the target building routine or alternatively as step 10. The shortages incurred by one or more other specified rights are added to the monthly target of the current right determined in step 1 above. *DO* record field 2 moves consideration of the *BU* record to step 15 or step 20 of the target building process. If the *BU* record is considered in step 2 or 10, the *BU* record will always develop a target equal to the total monthly shortage during the prior month for the specified water right(s).
3. The optional drought index defined by a set of *DI/IS/IP* records modifies any target set in steps 1 and 2 above as a function of reservoir storage. A negative *DINDEX* entered on the

WR or *IF* record switches application of the drought index until step 6. *DO* record field 4 moves consideration of the drought index to step 18 of the target building process.

4. One or multiple *TO* records may be used to continue to build a diversion or instream flow target as a function of a variable selected by *TOTARGET* in *TO* record field 2. The *TO* record based target is combined with the target determined in the preceding steps by either taking the maximum or minimum or by adding. Lower and upper limits may be placed on the targets. The first two of the three different options for applying limits are applied here. The third variation is activated by *TOTARGET*=10 with the limits applied later as step 7. A continuation option allows the target building to continue using the next *TO* record. In a daily simulation, step 4 *TOTARGET* options -1, -2, -3 and -5 involve computing the target as a function of total flow in the previous month. *TOTARGET* option -4 refers to the storage volume at the end of the previous month. *DO* record field 3 moves consideration of the *TOTARGET* options to step 16 of the target building process.
5. A time series of monthly targets for each month of the hydrologic period-of-analysis may be entered on *TS* records. The manner in which a *TS* record target is combined with the preceding intermediate (steps 1-4 above) target is specified by parameter *TSL*.
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 specified reservoirs. The drought index may be applied at this sixth step of the sequence or as step 3 above. *DO* record field 4 moves consideration of the drought index to step 18 of the target building process.
7. *TOTARGET*=10 in *TO* record field 2 results in *TO* record fields 5 and 6 limits being applied at this point in the computations. In a daily simulation, when applying the *TOTARGET*=10 option in step 7, the limit on either the target or quantity setting target is applied to the monthly target value prior to distribution to daily target amounts. *DO* record field 3 moves consideration of the *TOTARGET*=10 option to step 17 of the target building process.
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 volume of the defined variable falls 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. *DO* record field 5 moves consideration of *FS* and *CV* record options from step 8 or 9 to step 19 or 20 of the target building process.
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. 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.
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. *DO* record field 2 moves consideration of the *BU* record to step 15 or step 20 of the target building process.
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. Steps 11 and 12 occur at the

end of either the daily or monthly target building process. In a daily simulation, the steps 11 and 12 application of *SO* record limits occurs at the end after step 22.

12. The target is adjusted for the annual or seasonal diversion or regulated flow limits of *SO* record field 10. Step 12 is the end of the 12-step procedure for building a monthly target. Step 13 begins the conversion from of monthly target to a daily target. In a daily simulation, the steps 11 and 12 application of *SO* record limits is moved to the end of the 22-step target building procedure after step 22.

Distributing the Monthly Target to the Days of the Month

13. The monthly target set in the preceding steps 1 through 12 is distributed to daily targets as specified by *JU* and *DW* record parameters *ND* and *SHORT*. If *ND* is zero, the monthly target is divided by the number of days in the month to create a uniform target distribution. With *ND* set to a positive integer, the monthly target is uniformly distributed over the first *ND* days of the month. The *SHORT* option is combined with the *ND* option to recover shortages during subsequent days of the month. Shortage recovery is applied in step 22.

Steps in Building or Adjusting the Daily Target

14. *DW* record parameter *XDAY* moves consideration of *WR* or *IF* record targets to step 14 of the target building process. The *AMT* value in *WR* or *IF* record field 3 is directly used as daily target amounts. If the *JU* or *DW* record *ND* option is not activated (*ND* = 0), *XDAY* will result in the *WR* or *IF* field 3 target being used as the daily target in every day of the month. If the *JU* or *DW* record parameter *ND* is set to a positive value, it will be considered in step 13 for any monthly target built in steps 1 through 12, as well as considering any *WR* or *IF* field 3 target as the daily target in the first *ND* days of the month in step 14.
15. *DO* record field 2 moves consideration of the backup *BU* record shortages to step 15. *BU* record shortages considered here use the current day shortage of the specified water right(s) for each day of the month that a shortage is generated by the specified water right(s).
16. *DO* record field 3 moves consideration of *TO* record options from step 4 to step 16. *TO* record options will be applied in every day of the month unless the *ND* option is activated. If the *ND* option is used, the *TO* records will only be applied in the first *ND* days of the month. The preceding-period *TO* record options (*TOTARGET* = -1, -2, -3, -4 or -5) considered here are always based on flow or storage volume in the preceding day.
17. *DO* record field 3 moves the *TO* record options of step 7 to step 17. The options are applied in every day of the month in step 17 unless the *ND* option is activated. If the *ND* option is used, the *TOTARGET*=10 option will only be applied in the first *ND* days of the month.
18. *DO* record field 4 moves consideration of drought index defined by a set of *DI*, *IS*, *IP*, and *IM* records to step 18.
- 19 and 20. *DO* record field 5 moves activation of the flow switch *FS* and cumulative volume *CV* record options from steps 8 and 9 to steps 19 and 20.
21. *DO* record field 2 moves consideration of the *BU* record shortages to step 21. *BU* record shortages considered here will always use the current day shortage of the specified water right(s) for each day of the month that a shortage is generated by the specified water right(s).

22. If *JU/DW* record parameters *ND* and *SHORT* are greater than zero, any shortages incurred in days prior to the end of the month are eligible to be recovered during later days of the month subject to water availability. To attempt to recover a shortage in a subsequent day of the month, the daily target built in steps 1 through 21 must be less than the maximum daily target built in steps 1 through 21 in any previous day of the month. The amount of shortage that will be attempted for recovery is equal to the maximum daily target built in steps 1 through 21 minus the current day target as developed in steps 1 through 21. The shortage recovery target is added to any daily target amount built in steps 1 through 21 above.

Limitations on Withdrawals from Reservoir Storage

The parameter *NDSBU* in *DW* record field 6 and the following discussion thereof are relevant only for type 2 water rights and only when the *ND* and *SHORT* options described above are activated. Type 2 water rights supply a target from stream flow depletions as long as stream flow is available and then switch to supplying the target from withdrawals from storage. Type 2 water rights supply targets from reservoir storage but do not refill the storage in the reservoir.

The optional feature activated by *NDSBU* addresses the complexity of using stream flows, rather than reservoir storage, to meet targets during months that have low or zero flows early in the month and higher flows occurring during later days of the month. Water rights with access to reservoir storage will not incur shortages as long as water is available from storage. With the *ND* option activated, the target is assigned to the first *ND* days of the month. With inadequate stream flow available during the first *ND* days of the month, water is withdrawn from reservoir storage even though flows may be high later in the month. This situation results in a reservoir experiencing greater draw-downs in a daily simulation than in a monthly simulation.

NDSBU in *DW* record field 6 is an integer number of days representing the last *NDSBU* days of the month. When *NDSBU* is blank or 0, the option is not activated and reservoir storage is available to meet any shortage in any day of the month for a Type 2 *WR* record water right with an associated reservoir. If *NDSBU*, *ND*, and *SHORT* are all greater than zero, use of reservoir storage to meet the daily target is not allowed until the final *NDSBU* days of the month. Whereas the *ND* option is defined as days from the beginning of the month, *NDSBU* is defined as the number of days until the end of the month. If this option is adopted, *NDSBU* should be set equal to or greater than *ND* to ensure that the entire monthly target can access reservoir storage in the situations where no stream flow depletions are possible.

Overview Summary of Daily *SIMD* Simulation Features Covered in Chapters 2 and 3

Monthly datasets from the TCEQ Water Availability Modeling (WAM) System or other monthly WRAP input datasets may be converted to a daily model, resulting in both daily and monthly versions of the dataset for a particular river basin. Alternatively, a daily WRAP model may be developed directly without an accompanying monthly version. Developing a *SIMD* daily simulation model involves various choices in combining a variety of user-selected options associated with the modeling capabilities outlined in Table 2.4 and described in the different chapters of this manual. The features listed in Table 2.4 are related to each other in various ways. Choices of options to adopt for routing parameter calibration, flow disaggregation, target setting, forecasting, routing, and next-day placement of routed flows are interconnected.

Table 2.4
Outline of Daily Simulation Features

Disaggregation of Quantities from Monthly to Daily in SIMD (Chapter 2)

- Naturalized Stream Flows
 - Daily flows provided as input*
 - Disaggregation of monthly flows to daily flows*
 - uniform distribution
 - linear spline interpolation
 - linear interpolation with variability adjustment
 - reproduction of daily flow patterns
- Diversion, Hydropower, and Instream Flow Targets
 - uniform distribution of monthly targets to daily
 - *ND/SHORT* options for varying targets during month
 - target-building options

Flow Routing and Flow Forecasting in SIMD (Chapter 3)

- Forward and Reverse Routing of Flow Changes
 - lag and attenuation method
 - Muskingum adaptation
- Forecasting Supply Availability and Flood Release Capacity

Other Stream Flow Accounting Features of the SIMD Simulation (Chapter 3)

- Next-Day Placement of Routed Flow Changes
 - at the beginning of the next-day simulation
 - within the water rights priority sequence
- Negative Incremental Flow Options
- Routing Adjustments to Maintain Volume Balance

Calibration of Routing Parameters (Chapter 4, Appendices A and B)

- statistical analysis of flow changes (Program *DAY*)
- optimization procedures applied to entire hydrographs (Program *DAYH*)
- conventional Muskingum calibration using entire hydrographs (*DAYH*)

Other Major New Modeling Capabilities Added with the Daily Modeling System

- Flood Control Reservoir Operations (Chapters 5 and 7)
 - High Pulse Environmental Flow Requirements (Chapter 6 and 8)
-

Disaggregation and Aggregation (Chapter 2)

Daily naturalized flows may be provided directly in a *SIMD* input DSS or DIF file without monthly flows. Alternatively, daily flows may be developed by disaggregation of monthly naturalized flows using optional methods incorporated within *SIMD*. The standard recommended flow disaggregation method is based on replicating daily flow patterns and monthly totals. Other

more approximate options can be applied in the absence of daily pattern flow hydrographs. HEC-DSSVue facilitates compilation and analysis of daily flows. Daily flows are compiled for selected control points, which are typically located at stream gaging stations. An automated procedure within *SIMD* repeats the input daily pattern hydrographs at any number of other control points. The automatic flow repetition assignments are subject to user modifications.

Monthly reservoir evaporation-precipitation depths are uniformly distributed to daily depths. *SIMD* provides no other alternatives for disaggregating evaporation-precipitation rates.

Options for uniformly or non-uniformly distributing monthly diversion, hydropower, or instream flow targets to daily amounts are provided in *SIMD*. Monthly targets may be evenly divided into daily amounts, and a shortage declared any time a daily target is not fully met. Options activated by the parameters *ND* and *SHORT* entered on the *JU* or *DW* records provide an alternative approach to setting targets for situations characterized by some degree of flexibility in shifting demands over the month or storing a volume of water equivalent to one or multiple days of use. The *ND* option allocates the monthly target to a specified *ND* number of days beginning in the first day of the month. The daily target amount during the *ND* days is the monthly target divided by *ND*. The *ND* option may be combined with the *SHORT* option that shifts targets to subsequent days of the same month as necessary to match demands with available stream flows to prevent or reduce shortages in meeting monthly targets.

Target-building options activated by *TO*, *SO*, *FS*, *CV*, *DI*, *BU*, and other DAT file records that were originally developed for monthly *SIM* simulations are adapted within *SIMD* for daily applications using the *DO* record. When changing time-steps from monthly to daily, model-users should review monthly operating rules defined with *TO*, *SO*, *FS*, *CV*, *DI*, *BU*, and similar records to assure that daily river/reservoir/use system operations are modeled appropriately.

All of the *SIM/SIMD* simulation results time series variables recorded in the output OUT file for a monthly simulation, and defined in the *Reference Manual*, are also computed and recorded as sub-monthly (daily) amounts in the output SUB file for a *SIMD* daily simulation. Daily simulation results can be aggregated to monthly quantities and recorded in the OUT file. Program *TABLES* works with both monthly quantities from a *SIM/SIMD* OUT file and sub-monthly (daily) quantities from a *SIMD* SUB file. Annual series can also be derived with the *TABLES* DATA record from any of the simulation results variables or transformations thereof using the daily or monthly data in the *SIMD* SUB and OUT output files.

Daily and monthly *SIM/SIMD* simulation results are recorded in the same DSS file, which can be created by either *SIM/SIMD* or *TABLES*. *HEC-DSSVue* is applied in the same manner in organizing, analyzing, and displaying either daily or monthly simulation results.

Flow Routing and Flow Forecasting (Chapter 3)

The water accounting computations in the *SIMD* daily simulation model are basically the same as performed in a *SIM* or *SIMD* monthly simulation with extensions added as necessary. Modifications for daily water accounting stem primarily from the need to (1) translate flow changes to future days and (2) consider stream flow conditions in future days in accessing the volume of water supply or flood release capacity available in the current day.

Flow routing and forecasting are covered in Chapter 3. Forecasting considers future days in determining the volume of stream flow available for *WR* record water supply rights and channel capacity available for *FR* record flood control operations. Routing in *SIMD* consists of modeling the timing and attenuation of changes to stream flow. The purpose of forward routing is to adjust stream flows in current and future days at downstream locations for the effects of stream flow depletions, return flows, and other flow changes resulting from water right actions at control points located further upstream. Reverse routing is incorporated in flow forecasting to replicate the effects of forward routing of flow changes in the determination of flow availability for *WR* record rights and available channel capacity for *FR* record flood control operations. The same routing method and routing parameters are applied in both forward and reverse routing.

The lag and attenuation routing method was developed specifically for routing flow changes in *SIMD* and is the recommended option for most WRAP applications. An adaptation of the Muskingum method is also included in the modeling system. Programs *DAY* and *DAYH* provide options, covered in Chapter 4, for calibration of routing parameters.

Forecasting in *SIMD* deals with the effects of routing flow changes to future days. Flow forecasting is highly uncertain in the real world but is important to maintaining water right priorities in a daily computational time step model. Simulation of flood control reservoir system operations is also dependent on flow forecasting. Flow forecasting in *SIMD* is based on a two-simulation process repeated at each time step. A forecast simulation covering the forecast period is followed by a single time step actual simulation. The sole purpose of the initial forecast simulation is to obtain information about future stream flow for use in the actual simulation.

Reverse routing is automatically incorporated in the forecast simulation. The forecast period, in days or other sub-monthly time interval, over which future flows are predicted, is set automatically within *SIMD* for each individual *WR* record and *FR* record water right based upon the results of the reverse routing computations. WRAP users optionally can control setting of forecast periods with *JU*, *DW*, and *FF* record parameters which over-ride the automated procedure. However, the default automated determination of forecast periods within *SIMD* should be adopted unless there are specific reasons for user-specification of the forecast periods.

The default forecast period used in simulating *WR* record water rights is automatically computed within *SIMD* as twice the maximum routing period, which is the longest time required for the effects flow changes at any control point to reach the outlet based upon the routing computations. Forecasting of available channel capacity to accommodate releases from flood control pools is automatically determined within *SIMD* based on reverse routing between *FF* record downstream control points and *FR* record reservoirs.

Forecast simulations are necessarily approximate due to reasons noted below. However, the approximations are somewhat mitigated by updating the forecast simulation again at the beginning of each time step. Consider a day that is five days in the future ahead of the current day in a simulation that has a forecast period of seven days. This future day is referred to here as day 5. The three considerations noted below are all relevant to water supply (*WR* record rights), and the first two are relevant to flood control (*FR/FF* record rights).

- Cumulative effects of changes to naturalized flow in day 5 for water right actions occurring in days before the current day are known in the 7-day forecast simulation.

- The forecasted effects on stream flow of water right actions occurring during the current day and each day of the 7-day forecast period are approximated based on the latest simulation which is the actual simulation performed for the day preceding the current day.
- The availability of flow in day 5 does not reflect protecting flow available to senior rights in future days past the 7-day forecast period. Flow availability for a water right in the current day depends upon flows available to senior rights in future days which, in turn, depend upon flows available further into the future, and so forth into the indefinite, if not infinite, future. Though the effects of protecting senior rights in the future on stream flow availability today diminish as the model looks further into the future, there is no defined conceptual limit. However, an updated 7-day forecast simulation is repeated for the actual simulation each day.

Other Stream Flow Accounting Features of the SIMD Simulation (Chapter 3)

Two alternative strategies selected by the *JU* record *WRMETH* and *FRMETH* and *WR* record *RFMETH* are included in *SIMD* for carrying routed stream flow changes forward to the next time step. *WRMETH* option 2 places flow depletions associated with each individual right within the priority sequence in order to protect senior rights. This protects senior rights but allows erroneous *double-taking* of water because senior rights are allowed to take stream flow that has already been depleted by junior rights in previous days. The default *WRMETH* option 1 places the routed flow depletions at the beginning of the priority sequence, thus potentially affecting any water rights. Forecasting is adopted along with placement option 1 to properly protect senior rights during a forecast period by constraining junior rights in preceding days.

Selection of negative incremental flow option is controlled by input parameter *ADJINC* on the *JD* record. *ADJINC* option 7 is recommended standard for applications in which routing is adopted for reasons noted in the next paragraph. *ADJINC* option 1 considers all of the downstream control points identified in the reverse routing and thus may restrict the amount of flow available to a water right more than option 7 but is also applicable with routing.

The amount of stream flow available to a water right in Task 1 of Table 3.1 is the minimum *CPFLOW* array available flows in the current and forecast days at the control point of the water right and selected downstream control points. The reverse routing algorithm in *SIMD* delineates a matrix of downstream control points and future days that will be affected by a particular water right in the current day along with the effects of routing and channel losses on the flow changes resulting from the water right. The *CPFLOW* array available flows at these downstream control points reflect both the effects of senior rights and negative incremental flows. *JD* record *ADJINC* option 7 further restricts the downstream control points identified in the reverse routing to those at which senior rights are located. *ADJINC* option 7 is considered the most realistic approach for dealing with negative incremental flows in future days if forecasting is activated.

The following issue is different than the negative incremental concern of the preceding two paragraphs. Routed stream flow depletions may generate negative values in the *CPFLOW* array from which available, regulated, and unappropriated flows are derived. *SIMD* sets these negative flows to zero and adjusts the flow in the next time step to compensate. Thus, long-term volume balances are maintained though the volume balance may be violated in individual time steps. *JT* record *NEGCP* writes monthly totals of these daily negative flows in the message file.

CHAPTER 3 FLOW ROUTING AND FORECASTING

Routing consists of modeling the downstream translation and attenuation of changes to stream flow. The purpose of forward routing is to adjust stream flows in current and future days at downstream locations for the effects of stream flow depletions, return flows, and other flow changes resulting from water right actions at control points located further upstream. Reverse routing is incorporated in forecasting to replicate the effects of forward routing. The purpose of flow forecasting is to allow future days to be considered in determining the volume of stream flow available for water supply and channel capacity available for flood control operations.

Flow routing and forecasting are incorporated in a daily *SIMD* simulation as outlined in Table 2.4 and summarized in the last section of the preceding Chapter 2. The mechanics of the routing and forecasting techniques are described in the present Chapter 3. Routing and forecasting are integral components of the *SIMD* water accounting procedures.

Overview of the *SIMD* Water Accounting Procedures

The *SIMD* simulation steps through time. At each time step, computations are performed for each water right in priority order. With either a daily or monthly simulation, as each set of water management and use requirements is considered in the water right priority loop, the tasks described in Table 3.1 are performed. Flow forecasting with reverse routing is performed in conjunction with Task 1. Routing of flow adjustments is performed in conjunction with Task 4.

Table 3.1
Computations Repeated for Each Water Right at Each Time Step

-
- Task 1: Availability Determination. – The amount of stream flow available to the water right is the minimum of the control point flow *CPFLOW* array available flows at the control point of the water right and at relevant control points located downstream, optionally adjusted for channel losses and/or routing. In simulating flood control operations, the amount of channel flood flow capacity below maximum allowable non-damaging limits is determined considering the control point of the flood control right and pertinent downstream control points.
- Task 2: Target Set. – The water supply diversion target, hydroelectric power generation target, minimum instream flow limit, or non-damaging flood flow limit is set.
- Task 3: Water Right Simulation. – For the water right being considered, decisions are made regarding reservoir storage and releases, water supply diversions, and other water management/use requirements, and appropriate actions are taken. Net evaporation volumes are determined. Water balance accounting computations are performed.
- Task 4: Flow Adjustment. – The *CPFLOW* array used to determine water availability and remaining flood flow capacity in Task 1 is adjusted for the effects of the Task 3 water management and use actions associated with that particular water right.
-

The *CPFLOW control point flow availability array* represents available stream flow amounts at the current step in the water right priority-based simulation computations considering each control point location individually. At the beginning of the simulation time step, the *CPFLOW* array is populated with naturalized flows plus *CI* and *FA* record inflows and next-period return flows from the preceding time step. The *CPFLOW* array is applied in Task 1 of Table 3.1 to determine stream flow availability for each water right in the priority sequence. In Task 4 in Table 3.1, the amounts in the array are adjusted in the water rights computational loop nested within the time step loop to reflect the impacts of each right. At the end of the simulation time step, the array is used to determine regulated and unappropriated flows.

Flow Forecasting and Routing

Flow forecasting in *SIMD* is the process of considering future flows over a forecast period in determining water availability for *WR* record water rights and available flood flow channel capacity for *FF/FR* record flood control rights. The forecast period set automatically by *SIMD* may be replaced by a user-specified forecast period for all or individual water rights.

Routing in *SIMD* is the process of modeling time lag and storage effects as adjustments to river flows for upstream water control/use actions are propagated downstream over time. Two alternative routing methods are incorporated in *SIMD*. A lag and attenuation routing method developed specifically for *SIMD* is the recommended standard default option. An adaptation of the Muskingum routing method is also incorporated in *SIMD*. Both alternative methods have two parameters representing flow travel time and storage attenuation in a river reach.

The relevance of flow forecasting and routing depends upon the relative magnitude of computational time steps and flow travel times between control point locations. The effects of reservoir operations and other water management and use actions usually propagate through a river/reservoir system in less time than a month. Forecasting and routing are typically not applied in a monthly time step simulation for even very large river systems. Forecasting and routing are typically appropriate for daily simulations of relatively large river systems. With time steps of one-fifth or one-fourth of a month, forecasting and routing may or may not be appropriate depending upon the reach lengths and flow travel times involved in the simulation. The effects of forecasting and routing on simulation results are also affected by the options for setting daily diversion, hydropower, and instream flow targets discussed in Chapter 2.

Routing Adjustments for Next Day Placement of Routed Flow Changes

SIM and *SIMD* monthly simulation computations always maintain volume balances that properly account for all inflows, outflows, and changes in storage. However, due to inaccuracies in forecasting and routing, control point flow availability array values may drop below zero in the *SIMD* computations. *SIMD* sets negative regulated flows equal to zero and postpones consideration of the necessary amount of routed depletions until the next time step. The routed depletions are applied to regulated flows at the start of the next time steps until regulated flow meets or exceeds the amount of routed depletions. Adjustment of the timing of routed depletion consideration allows stream flows to remain at or above zero and also maintains the long-term volume balance. Parameter *RTGSMM* in *JT* record field 12 activates an option in which monthly totals of routing adjustments are tabulated in the message file on a control point basis.

Options for next-day placement of routed flows controlled by *JU* record parameters *WRMETH* and *WRFCST* are described in Chapter 4 of the *Users Manual*. With either *WRMETH* or *WRFCST* option 1, the summation of routed flow adjustments from the preceding day is incorporated in the *CPFLOW* array at the beginning of the priority sequence for the current day. Thus, actions of water rights in preceding days may affect stream flow availability in the current day for any water rights, including senior as well as junior rights. With either *WRMETH* or *WRFCST* option 2, flow adjustments generated by each individual water right are maintained within the priority sequence. *WRMETH* and *WRFCST* option 2 protects senior rights in the current days from stream flow depletions by junior rights during preceding days.

WRMETH and *WRFCST* option 1 minimizes needs for routing adjustments, but does not protect senior rights in the current day from actions of junior rights in previous days. *WRMETH* and *WRFCST* option 2 protects senior rights but, with imperfect routing and imperfect or no flow forecasting, allows senior rights to take stream flow that has already been depleted by junior rights in previous days. Thus, the potential for making routing adjustments is increased.

WRMETH is used to place routed changes to flow that originate in the non-forecast simulation, also referred to as the final real simulation. Stream flow depletions or reservoir releases by *WR* and *FR* record rights that originate in the non-forecast simulation are permanent and are recorded in the simulation output files. The changes to flow made in the non-forecast simulation are routed downstream and affect the values of regulated flow at all downstream control points and may affect water availability for other water rights.

WRFCST controls the placement of changes to flow made within the forecast simulation. If forecasting is not performed, the value of *WRFCST* on the *JU* record is ignored. *WRMETH* and *WRFCST* may select the same or different placement options.

The details of the forecast simulation are discussed later in this chapter (Table 3.2). The forecast simulation provides water rights the necessary downstream future values of *CPFLOW* for determining present day water availability in the non-forecast simulation. Water right actions in the forecast simulation are simulated in the same manner as in the non-forecast simulation. However, water rights are simulated during the forecast with future downstream values of *CPFLOW* from the previous forecast. Therefore, the changes to flow made by water rights during the forecast simulation are approximate due to daily revisions to the forecasted values of *CPFLOW* as well as the outcome of final water right actions in the non-forecast simulation.

Final changes to flow that are made outside of the forecast simulation will continue to be placed either before or within the priority sequence according to *WRMETH* in future days until the changes to flow reach the basin outlet. If a forecast simulation is activated by *JU* record field 7, those changes to flow that are made outside of the forecast simulation will continue to be placed either before or within the priority sequence according to *WRMETH* during the forecast simulation. Therefore, during the forecast simulation, if different options are chosen for *WRMETH* and *WRFCST*, two different placements for changes to flow may occur. If *WRMETH* option 1 and *WRFCST* option 2 are selected, changes to flow for all *WR* and *FR* record rights that are made in the non-forecast simulation in preceding days will continue to be placed before the priority sequence. Changes to flow being made within the forecast simulation will be placed within the priority sequence for the remainder of the forecast simulation or until the change to

flow reaches the basin outlet. A selection of *WRMETH* option 2 and *WRFCST* option 1 will have the opposite placement configuration as described above.

WRMETH option 1 is less likely to result in routing adjustments because all past water right changes to flow are applied to the *CPFLOW* array before new changes to flow are made in the current day. Adjusting the *CPFLOW* array for all final changes to flow from past days in the non-forecast simulation before the priority sequence also provides a more realistic representation of stream flow conditions for current day water right considerations. Senior rights should not be negatively impacted by the actions of junior water rights and especially the actions of junior rights during the forecast simulation to obtain future downstream *CPFLOW* values for determining current day water availability. *WRFCST* option 2 provides senior rights future downstream *CPFLOW* values that are not affected by future junior water right actions. Combining *WRMETH* option 1 with *WRFCST* option 2 may produce simulation results that optimally minimize routing adjustments while maximizing water availability for senior rights.

Negative Incremental Flow Options

ADJINC in *JD* record field 8 is a switch for selecting between options associated with the determination of the amount of stream flow available to a water right in Task 1 of Table 3.1 based on *CPFLOW* array flows at downstream control points. The alternative *ADJINC* options are described in the *Reference* and *Users Manuals* from the perspective of a monthly *SIM* simulation. The *ADJINC* options represent alternative approaches for dealing with the effects of downstream senior rights and negative incremental naturalized flows in checking the *CPFLOW* array available flows. *ADJINC* options 2, 3, and 4 activate flow adjustments that deal with negative incrementals. The options differ in the selection of downstream control points to include in the *CPFLOW* array flow comparison.

Negative Incremental Flows

Naturalized, regulated, and unappropriated flow volumes, and *SIM/SIMD* algorithms are all based on cumulated total flows at each control point, rather than incremental local flows between control points. However, with a monthly simulation interval (with no routing), the term *negative incremental flow* is applied to describe situations in which the naturalized flow volume for a particular time step at a control point is less than concurrent flows at control points located upstream. Negative incremental means the flow is decreasing in a downstream direction in that time interval. With a monthly time step, by definition, negative incrementals do not exist in a naturalized flow dataset if flows in each time step always increase going downstream.

A daily simulation is complicated by routing which extends the concept of negative incremental flows across multiple time steps. With routing, incremental flows at a particular control point are viewed conceptually as total naturalized flows originating from the current and preceding days routed from one or more (multiple-tributary) adjacent upstream control points less the total naturalized flow at the particular control point. These incremental flows are usually positive but may be negative. The concept of negative incremental flows is fundamental to both daily and monthly simulations even though the computations are based on total flows. Alternative options for dealing with negative incremental flows can significantly affect simulation results in either a monthly or daily model.

Relevant Control Points Considered in the Determination of Available Flow

In Task 1 of Table 3.1, the stream flow available to a water right is determined as the minimum of the *CPFLOW* array flows at the control point of the right and selected control points located downstream. Without routing and forecasting, only *CPFLOW* array available flows in the current period are considered. With routing and forecasting, *CPFLOW* flows in the current day and each day of the forecast are considered. For a particular water right, the set of control points included in determining flow availability includes the control point of the water right and those additional control points that meet all three of the following criteria:

1. located downstream of the control point of the water right
2. identified in the routing and reverse routing as discussed later in this chapter
3. location of senior water rights if either *ADJINC* option 5, 6, or 7 is activated

Routing and reverse routing determines combinations of future days and control points to be included in the flow availability computations. The third criteria listed above for selecting downstream control points is applicable only if *JD* record *ADJINC* option 5, 6, or 7 is selected.

The amount of stream flow available to a water right in Task 1 of Table 3.1 is the minimum *CPFLOW* array available flows in the current and forecast days at the control point of the water right and selected downstream control points. Flow at downstream control points may be the minimum in the *CPFLOW* array comparison and thus limit the amount of flow available to the water right located upstream only if one or more of the following conditions occur:

1. junior rights decrease the flows at one or more of the downstream control points
2. senior rights decrease the flows at one or more of the downstream control points
3. negative incremental flow situations affect the flow availability computations

The purpose of forecasting is to prevent junior rights from reducing the stream flow available to senior water rights in future days. Therefore, with forecasting activated, the above list of factors affecting flow available to a particular right is reduced to the effects of senior rights and negative incremental flows. Thus, *ADJINC* options 5, 6, and 7 limit the search for the constraining minimum *CPFLOW* flow to the control points of the water right and downstream senior rights.

Options Activated by *ADJINC* in *JD* Record Field 8

Negative incremental flow options 1, 2, 3, 4, and 5 date back to early versions of the monthly *SIM*. Option 1 considers all downstream control points in selecting the minimum flow quantity from the *CPFLOW* array and applies no incremental flow adjustments. Options 2 and 3 are seldom if ever used. Option 4 has been the recommended standard for a monthly simulation. Option 5 is also commonly used for monthly simulations, but is the only *ADJINC* option that cannot be activated with a daily simulation.

As explained in Chapter 3 of the *Reference Manual*, options 4 and 6 involve a flow adjustment defined as the minimum amount of flow that must be added to the naturalized flow at a control point to alleviate all negative incremental naturalized. *SIMD* computes and applies negative incremental flow adjustments for a daily time step in the same manner as the monthly *SIM*. *SIMD* first determines daily naturalized flows at all control points and then computes daily negative incremental flow adjustments. *SIMD* applies daily negative incremental flow

adjustments in the same manner that *SIM* applies monthly adjustments. In determining stream flow available for *WR* record water rights and filling *FR* record flood control reservoir storage at a particular control point, the adjustment amounts are added to control point flows at downstream control points but not at the control point of the water right. Since the negative incremental flows are defined by concurrent upstream and downstream flows in the same time step, options 4 and 6 are generally not applicable for a daily simulation that includes forecasting.

The new *ADJINC* options 6, 7, and 8 are defined as follows. Relevant senior rights are those that appropriate stream flow, which excludes types 3, 4, and 6 (*WR* record field 6).

Option 6 is same as option 4 except the downstream control points used in selecting the minimum flow from the *CPFLOW* array are limited to the sites of relevant senior rights.

Option 7 is same as option 1 except the downstream control points used in selecting the minimum flow from the *CPFLOW* array are limited to the sites of relevant senior rights.

Option 8 incorrectly ignores all downstream control points. The *CPFLOW* array flow at the control point of the water right is assumed to be the flow available to the water right.

Any of the eight *ADJINC* options can be adopted in either *SIM* monthly or *SIMD* daily simulations, except option 5 is not allowed in a daily simulation. A daily *SIMD* simulation can be performed either with or without forecasting. Option 7 is recommended for daily simulations with forecasting. Option 6 is recommended for daily *SIMD* simulations if forecasting is not employed. Option 1 restricts the flow amount available to water rights more than option 7.

Option 7 is designed to be the standard *ADJINC* option to be adopted whenever forecasting is employed, but can also be used in a monthly or daily simulation without forecasting. The downstream control points considered in the flow availability algorithm are limited to only those control points at which senior rights are located. Flows at downstream control points not affected by senior rights have no effect on water availability for the junior right. 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 features of option 5. Option 7 is option 1 with the limitation to senior right control points added.

Option 6 is identical to 4 except only the control points with senior rights are considered. Options 6 and 4 should yield essentially the same simulation results though option 4 is more conservative in assuring that flow cannot be over-appropriated. Option 8 allows investigation of the effects of junior rights not passing inflows to protect downstream senior rights.

Routing Changes to Flow

Routing in *SIMD* propagates flow changes through river reaches connecting control points. Water supply diversions and return flows and reservoir releases and storage refilling at a control point result in changes in stream flows at downstream control points. Routing in *SIMD* refers to the downstream propagation of changes resulting from an upstream change to stream flow. Reverse routing replicates the effects of routing in the procedure for forecasting flow availability for *WR* and *IF* record rights as explained later in this chapter in the section on forecasting.

In the monthly time step *SIM*, for a river reach without reservoir storage, outflow volume in a month equals the inflow in the month less channel losses. Likewise, without activation of the routing methods described here, in a daily *SIMD* simulation, outflow volume from a river reach in a day equals its inflow less channel losses. Routing simulates the storage effects (lag and attenuation) of a river reach on the relative timing of reach outflows and inflows.

Routing Flow Changes Associated with Water Rights

A reach refers to the segment of river between two control points. Routing parameters are entered on the *RT* record for the control point defining the upstream end of a river reach. Different parameter values may be entered for flow changes associated with flood control *FR* record reservoir operations and flow changes for *WR* record rights. If routing parameters are assigned for a control point, routing computations are performed resulting in lag and attenuation of flow changes originating at or passing through the control point. If routing parameters are not specified for a particular control point, flow changes originating at or passing through the control point are passed through the reach below the control point by simple translation without routing computations and thus without lag or attenuation. Without routing, outflow from a river reach in a time step equals the inflow in the time step less channel losses.

Channel losses are computed in both monthly *SIM* and daily *SIMD* simulations in both Tasks 1 and 4 of Table 3.1. In Task 4, routing computations are performed after the channel loss computations. The routed flow changes are then further adjusted for channel losses. *SIMD* routing in Task 4 is replicated as reverse routing in Task 1.

Routing occurs at a control point if and only if routing parameters are specified as input data for that control point. Routing computations normally simulate flow attenuation and lag in the river reach below the specified control point. However, the model user may choose to lump attenuation/lag effects in multiple reaches in routing computations at a single control point. The model user selects the control points at which routing is to be applied. In applications with significant flow travel times between control points, routing parameters may be provided for all control points, except the basin outlet. However, a *SIMD* model may include control points defining river reaches that are too short to meaningfully apply routing in a daily time step model. The larger river basins in the Texas WAM System have hundreds of control points, many of which are too closely spaced for meaningful routing. For complex datasets with numerous closely spaced control points, lag and attenuation effects may be aggregated to selected reaches.

Routed flow changes are used by *SIMD* to update the control point flow availability *CPFLOW* array in the water right priority sequence computations in conjunction with Task 4 described in Table 3.1. As the simulation steps through time, at a particular time step, the routing of incremental changes in stream flow is organized as follows.

1. Prior to the water rights computation loop, the *CPFLOW* control point flow availability array is adjusted for the effects of constant inflows from *CI* records and spills associated with *MS* record seasonal rule curve reservoir operations. Routing is applied to these flow changes prior to simulating water rights. Thus, the amount of water available to any or all water rights may be affected in current and future time steps.

2. As each *WR* record water right is simulated, the *CPFLOW* array is adjusted for the effects of past stream flow depletions and return flows that are routing through the control point network. With *JU* record *WRMETH* option 1 and *WR* record *RFMETH* options 2 and 4, future downstream changes from flow depletions and return flows, respectively, are aggregated and placed at the beginning of the next-day simulation. *WRMETH* option 2 and *RFMETH* options 2 and 4 apply routing separately for each individual right within the water rights priority sequence.
3. Flood control operations specified by the *FR* record are described in Chapter 5. Flow changes are associated with filling storage and subsequent releases from flood control pools. Parameter *WRMETH* on the *JU* record also controls whether routed flood flow depletion and release changes are placed at downstream control points at the beginning of the next-day simulation or within the priority loop computations.

Without adjustment, negative values would be generated in the *CPFLOW* array. When routed depletions exceed the flow at a control point, *SIMD* sets *CPFLOW* to zero and adjusts *CPFLOW* in the next time step to compensate. Thus, long-term volume balances are maintained through delayed application of routed depletions over individual time steps.

SIMD contains two alternative optional routing methods: (1) lag and attenuation and (2) Muskingum adaptation. Either of the methods may be activated at a particular control point, representing the stream reach or reaches below that control point. Optionally, routing may not be activated for particular control points. The general framework for incorporating routing into the *SIMD* simulation described in the preceding paragraphs is applicable to either of the routing methods. Either serves the same purpose within the *SIMD* simulation. Both approaches have analogous input parameters related to travel time and storage attenuation that are best determined through calibration. Calibration methods in *DAYH* are applicable to either routing method.

The lag and attenuation method is recommended for most water availability modeling applications. The lag and attenuation method is (1) designed specifically for *SIMD* for routing changes in flow, (2) easier to understand from the perspectives of both estimating values for the parameters and visualizing the routing computations in the simulation model, and (3) computationally stable with any control point spacing and reach travel times. The widely known Muskingum method was developed decades ago for routing entire flood hydrographs, not flow changes. The adaptation of the Muskingum flood hydrograph routing method (1) is based on an accepted method that has been extensively applied in many models for many decades for routing flood hydrographs with a small time step, (2) may exhibit computational instabilities, particularly with control points separated by very short travel times, and (3) is more applicable for studies focused on simulating flood control operations than for low and normal flows.

WRAP Lag and Attenuation Routing Method

The lag and attenuation routing method simulates the travel time and storage effects of a stream reach on flow changes for upstream diversions, return flows, reservoir releases, stream flow depletions for refilling reservoir storage, and *CI* record constant inflows. The following four parameters are entered on the *RT* record for a control point as the variables *RPARAMS(cp,I)* for *I* = 1, 2, 3, and 4.

- LAG* – lag time in days for water right *WR* record flow changes
- ATT* – attenuation in days for water right *WR* record flow changes
- LAGF* – lag time in days for flood control reservoir *FR* record flow changes
- ATTF* – attenuation in days for flood control reservoir *FR* record flow changes

The *LAG* and *ATT* parameters and *LAGF* and *ATTF* parameters are applied in identically the same manner, except *LAGF* and *ATTF* are applied only to stream flow changes associated with flood control reservoir operations. *LAG* and *ATT* are applied to all other stream flow changes. Thus, parameter values may be varied between flood conditions and more normal or low flow conditions. The following discussion is applicable to either normal or flood routing.

The unit of measure for the four parameters is actually the sub-monthly time step adopted for the *SIMD* application. However, units of days are adopted in this discussion since the day is expected to be the sub-monthly time step most often adopted. The four parameters are real (decimal) numbers, rather than integers, in days that may include a fractional portion of a day.

The routing procedure consists simply of lagging a flow changes *LAG* days and attenuating the changes over *ATT* days. The lag time *LAG* is measured from the end of day zero in which the diversion, return, flow, reservoir release, stream flow depletion for refilling reservoir storage, or *CI* record inflow occurred. The attenuation time *ATT* is measured from the front edge of the lag time *LAG*. The routing computations consist simply of dividing the total volume of the flow change uniformly over the period defined by *LAG* and *ATT*.

The lag and attenuation procedure is illustrated by an example in Figure 3.1. In this example, a diversion of 30 acre-feet occurs in day zero at a particular control point. The stream flow change at this control point consists simply of reducing the stream flow by 30 acre-feet in day zero. The routing consists of computing the corresponding change at the downstream control point. The input parameters *LAG* and *ATT* are 4.5 days and 3.0 days, respectively.

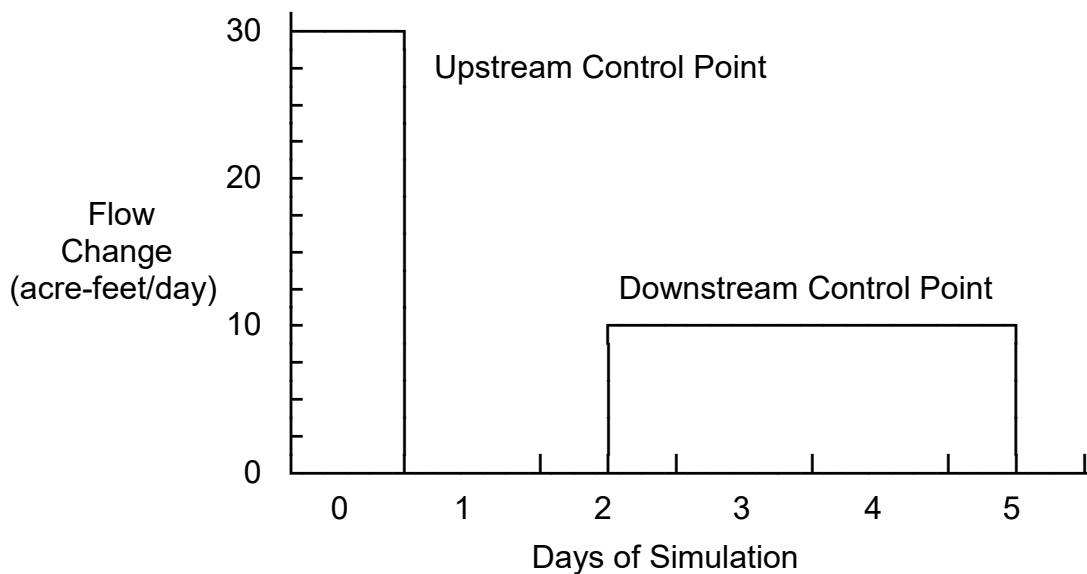


Figure 3.1 Routing for LAG of 4.5 Days and ATT of 3.0 Days

If channel losses occurred in the reach between the two control points (non-zero channel loss factor on *CP* record), the channel losses computations would be applied before the routing. However, for this example, the reach has no channel losses.

In Figure 3.1, the 30 acre-feet flow change is lagged by 4.5 days and attenuated over 3.0 days. The *LAG* of 4.5 days is measured from the end of day zero. The *ATT* of 3.0 days extends from the leading edge of *LAG* (middle of day 5) backwards for 3.0 days to the middle of day 2. The attenuation computation consists simply of dividing the 30 acre-feet flow change uniformly over the 3.0 day period defined by *LAG* and *ATT*. The routing results in the following flow changes at the downstream control point.

5.0 acre-feet in day 2
 10.0 acre-feet in day 3
 10.0 acre-feet in day 4
 5.0 acre-feet in day 5

The 30 acre-feet is distributed uniformly over the 3 day attenuation period which includes all of days 3 and 4 and half of days 2 and 5 of the *SIMD* simulation. The 5.0 acre-feet assigned to days 2 and 5 reflects only 0.5 day of the attenuation period falling within simulation days 2 and 5.

As another example illustrated by Figure 3.2, the 30 acre-feet flow change is lagged by 4.0 days and attenuated over 2.5 days. The routing results in the following flow changes at the downstream control point.

6.0 acre-feet in day 2
 12.0 acre-feet in day 3
 12.0 acre-feet in day 4

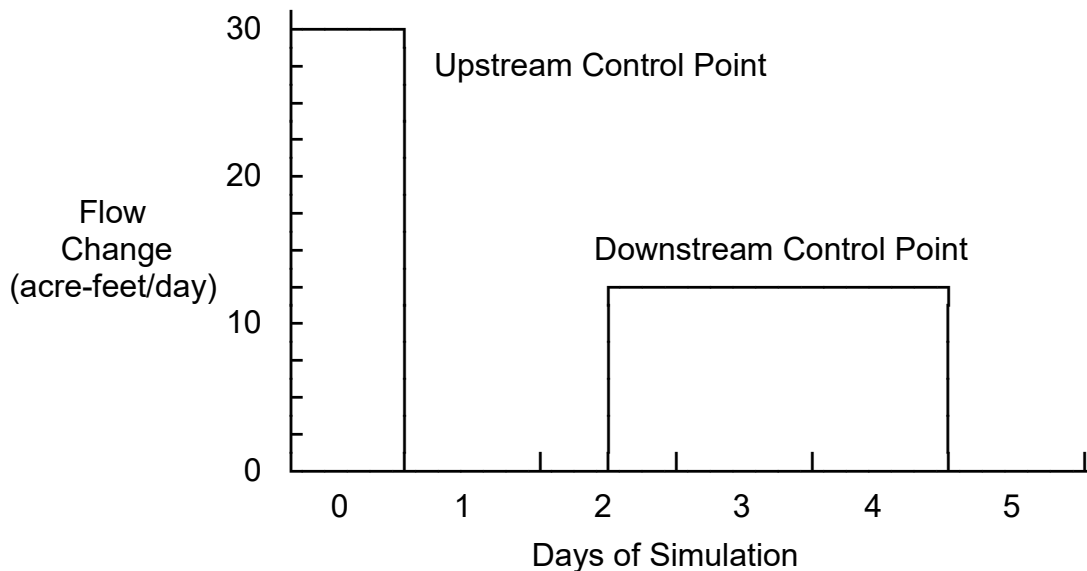


Figure 3.2 Routing for LAG of 4.0 Days and ATT of 2.5 Days

Muskingum Routing

The Muskingum method has been applied in many models over many years to routing flood hydrographs through river reaches and is described in many textbooks [9, 10]. The method dates back to a flood control study of the Muskingum River in Ohio by the Corps of Engineers in the 1930's. Muskingum routing has usually been applied for routing flood hydrographs. Given the discharge hydrograph at an upstream site, the corresponding hydrograph at a location further downstream is computed.

All hydrologic routing techniques are based on the continuity equation.

$$\frac{dS}{dt} = I(t) - O(t) \quad (3.1)$$

S denotes the total volume of water stored in the river reach at an instant in time (t). The derivative of storage with respect to time (dS/dt) represents a rate of change in storage at that instant in time. I(t) and O(t) denote inflow and outflow rates at an instant in time. For computational purposes, Equation 3.1 is rewritten as Equation 3.2.

$$\frac{S_T - S_{T-1}}{\Delta t} = \left(\frac{I_{T-1} + I_T}{2} \right) - \left(\frac{O_{T-1} + O_T}{2} \right) \quad (3.2)$$

The subscripts T-1 and T refer to the beginning and ending of the time interval Δt . Routing algorithms step through time with the inflow to the river reach known at both the beginning (I_{T-1}) and end (I_T) of each Δt . The storage (S_{T-1}) and outflow (O_{T-1}) at the beginning of Δt are also known from computations for the preceding time step. S_T and O_T are the unknowns computed at each time step. With two unknowns, a second flow versus storage relationship is required. Alternative hydrologic techniques differ in the second flow versus storage relationship that is combined with the continuity equation.

Muskingum routing is based on combining the continuity equation (Eq. 3.2) with a linear relationship between storage (S) in the river reach at an instant in time and a weighted instantaneous inflow (I) to the reach and outflow (O) from the reach.

$$S = K (X I + (1.0 - X) O) \quad (3.3)$$

The Muskingum routing equation (Eqs. 3.4a, 3.4b, 3.4c, and 3.4d) is derived by substitution of Eq. 3.3 for S_1 and S_2 into Eq. 3.2 and collecting and rearranging terms. Inflows (I) and outflows (O) in Eqs. 3.1 through 3.4 are defined at an instant in time. However, in applying the Muskingum method, some models including *SIMD* treat I and O as flow volumes or mean flow rates during a finite time interval (Δt). K and Δt have the same units of time.

$$O_T = C_A I_T + C_B I_{T-1} + C_C O_{T-1} \quad (3.4a)$$

$$C_A = \frac{0.5\Delta t - KX}{K(1.0 - X) + 0.5\Delta t} \quad (3.4b)$$

$$C_B = \frac{0.5\Delta t + KX}{K(1.0 - X) + 0.5\Delta t} \quad (3.4c)$$

$$C_C = \frac{K(1.0 - X) - 0.5\Delta t}{K(1.0 - X) + 0.5\Delta t} \quad (3.4d)$$

$$C_A + C_B + C_C = 1.0 \quad (3.5)$$

The routing parameters X and K are defined by Eq. 3.3 in which storage (S) is linearly related to a weighted combination of inflow and outflow ($XI+(1-X)O$). In general, K controls lag, and X controls attenuation in the Muskingum model of flow through a river reach. The parameter K represents flow travel time through the river reach and has units of time such as days. The dimensionless weighting factor X represents the relative influence of inflow versus outflow in determining the volume of water stored in the river reach at an instant in time.

Relating storage to a weighted inflow and outflow (Eq. 3.3) addresses the looped storage versus outflow relationship discussed in textbooks that is typically exhibited by flow in rivers. For a given flow rate (O) at the downstream end of a river reach, the volume of water stored in the reach is greater if the river stage at the downstream end is rising than if it is falling. Eq. 3.10 provides a simple means to represent control of storage by both inflow and outflow.

An X of zero implies that storage can be computed as a function of outflow only ($S=KO$) without considering inflow. The simpler convex routing method, also referred to in the literature as linear reservoir routing, is equivalent to Muskingum routing with a value of zero for X .

The parameter X is a weighting factor ranging from 0.0 to 1.0. In actual application, X must range between 0.0 and 0.5 to simulate flow attenuation. Natural river reaches have been found to often be characterized by a value for X of about 0.2. Without calibration studies, $X=0.2$ has sometimes been adopted for particular applications. The parameter K represents flow travel time and has been approximated by various methods for estimating travel time through a river reach [10]. Values for X and K are normally established by calibration based on observed flows. Calibration routines for computing K and X are included in the program *DAYH*.

Computational instabilities resulting in negative or otherwise unreasonable values for computed outflows are a problem with Muskingum routing if the river reach being modeled is too short or too long. McCuen [10] and others have suggested the following rule-of-thumb limits on K and X to avoid these problems.

$$2KX \leq \Delta t \leq 2K(1 - X) \quad (3.6)$$

$$0.0 \leq X \leq 0.5 \quad (3.7)$$

With a Δt of one day and X of 0.2, these limits imply that K should range between 0.625 and 2.5 days. If a river reach is too short, outflow may be assumed equal to inflow without routing. If a river reach is too long, it may be divided into two or more reaches with the outflow from one reach becoming the inflow to another.

SIMD checks the input values of K and X and reports a warning message to the MSS file if the parameters violate the above criteria. K is the more critical parameter for routing accuracy. Parameter calibration is usually relatively insensitive to changes in X . A common practice is to assume most river reaches are modeled with an X of between 0.0 and 0.3. The value of X will

decrease towards 0.0 as K increases to maintain numerical stability, and is physically related to increasing wave attenuation as travel time increases in the reach.

SIMD Adaptation of Muskingum Routing

SIMD is different than conventional routing applications because multiple incremental flow change volumes rather than total flow rates are routed. For example, if 5.4 acre-feet of water is either stored or diverted from the river at a particular control point, the stream flow at that control point and downstream control points is reduced. As the effects of this 5.4 ac-ft stream flow depletion propagates to river flows at downstream control points, the 5.4 ac-ft change may be modified by attenuation and lag effects modeled by routing as well as channel losses modeled by the channel loss equation described in the *Reference Manual*. The 5.4 ac-ft flow appropriation affects flows at downstream control points in the same day as the appropriation and in subsequent days.

The variables in Eqs. 3.1 and 3.2 are defined below from the perspective of routing in *SIMD* and are defined again later from the perspective of calibrating K and X in *DAYH*.

- Δt – day or other sub-monthly time interval
- K – parameter input on *RT* record in same units as Δt
- X – dimensionless parameter input on *RT* record, $0.0 \leq X \leq 0.5$
- S_T – storage volume at the end of time step T (used in calibration only)

Muskingum is a linear routing method based on Equation 3.4. The coefficients C_A , C_B , and C_C for a particular river reach are computed from the parameters K and X entered on a *RT* record for the control point defining the upstream end of the reach.

$$O_T = C_A I_T + C_B I_{T-1} + C_C O_{T-1} \quad (3.4a)$$

The outflow (O) from a river reach is the inflow (I) to the next downstream reach. Stated another way, the outflow (O) computed for a particular control point is the inflow (I) or at least a component of the inflow (I) at the next downstream control point. The variables in Eq. 3.4a are defined as follows, where subscripts T-1 and T denote the preceding and current time steps.

- I_{T-1} – volume of the change entering the control point during the preceding time step
- I_T – volume of the change entering the control point during the current time step
- O_{T-1} – volume of the change leaving the control point during the preceding time step
- O_T – volume of the change leaving the control point during the current time step

Different values of Muskingum K and X parameters may be assigned on the *RT* record for flow changes associated with *FR* record flood control reservoir operations versus *WR* record water right operations. Flow velocities are greater and travel times shorter for flood flows.

Flow Forecasting

Forecasts of future stream flows may be applied in both water supply and flood control operations. As discussed in Chapter 5, reservoir operations for flood control are based on making no release today that contributes to downstream flooding today or during future days. In

water supply operations, forecasting addresses the issue of water control and use decisions today affecting flows over the next several days from the perspective of the Task 1 stream flow availability determination outlined in Table 3.1. Since some lag time is required, perhaps several days, for flow changes to propagate downstream to the river system outlet, water supply diversions and return flows and multiple-purpose reservoir operations in the current time step affect downstream regulated flows in subsequent time steps. The *SIMD* simulation algorithms protect senior water rights from the actions of junior rights in the current and preceding days.

Flow forecasting in *SIMD* is defined as considering stream flow availability over a future forecast period (F_P) when determining water availability and flood flow capacity in conjunction with the previously described Task 1 of Table 3.1. The default is no forecasting, $F_P=0$. Without forecasting, *SIMD* only considers flows in the current time period in determining water availability and channel capacity. With forecasting, F_P future days are considered in the examination of flows at downstream control points. Forecasting is not relevant for rights at a site with no downstream control points. Forecasting is relevant only if routing is adopted.

Forecasting may be applied with *WR* and *FR/FF* record rights but not with *IF* record rights. Instream flow requirements (*IF* records) affect the amount of water available for *WR* record rights, but downstream water availability is not a factor in setting the instream flow targets. Likewise, downstream flow availability does not constrain hydropower releases or rights that do not make stream flow depletions. Forecasting does not affect water availability for types 3, 4, 5 or 6 *WR* record rights. Forecasting is applied in determining water availability for *WR* record rights making stream flow depletions for water supply diversions and refilling reservoir storage and in determining remaining channel capacity for *FR/FF* record flood control releases.

Reverse routing is incorporated in the forecasting procedure to account for the lag and attenuation effects of the routing of stream flow changes associated with water rights. Likewise, a reverse accounting for channel losses is incorporated in the forecasting procedure. The assessment of water availability in each future day of the forecast simulation is based upon the proportion of the stream flow depletion or return flow associated with a water right in the current day that travels to downstream control points in the current and future days.

Flow Forecast Period Parameters

Forecasting is activated as *FCST* option 2 in *JU* record field 7. The default *FCST* option 1 means no forecasting. Options related to forecast periods are selected in *JU* record fields 8 and 9, *DW* record field 2, and *FF* record field 5. These fields are left blank unless the user specifically chooses not to adopt defaults. As discussed below, *SIMD* automatically determines all parameters needed to control forecasting, though the user can over-ride these forecast period parameters by entries in *JU* record fields 8 and 9, *DW* record field 2, and *FF* record field 5.

Forecasting refers to both water supply (*WR* records) and flood control (*FR* and *FF* records). Forecasting is relevant to water supply for only *WR* record rights that involve stream flow depletions. Forecasting is not applied for instream flow *IF* record and types 3, 4, 5 and 6 *WR* record rights since they do not involve determinations of available stream flow. Forecasting is applied in the determination of available channel flow capacity for *FR/FF* record flood control operations.

The simulation forecast period (F_P) is the number of daily computational time steps into the future considered in determining water availability for a *WR* record right or remaining flood flow capacity for a *FR/FF* record right. Forecasting in *SIMD* is based on a forecast period (F_P) that may range from one day to the integer number of daily computational time steps in a year (365 days). A F_P of zero means no forecasting. Other time periods related to flow forecasting are defined below also as integer numbers in units of days.

The concept of a routing factor array (*RFA*) is described later in this chapter in the section entitled *Routing and Forecast Reverse Routing*. The ***RFA*** contains flow changes at a control point in each day expressed as a fraction of the total flow change at the control point.

The ***routing period*** for a water right is defined as the period of days over which the factors in the routing factor array (*RFA*) are non-zero, measured from the current day through the last future day with a non-zero factor in the *RFA*. The ***maximum routing period*** is the maximum of the routing periods for all of the water rights in the dataset. The routing periods for each water right and the maximum routing period are determined automatically within *SIMD*.

The ***simulation forecast period*** (F_P) is the number of future days over which the forecast simulation described in Table 3.5 is performed. By default, *SIMD* automatically sets F_P equal to twice the maximum routing period not counting the current day. *FPRD* in *JU* record field 8 over-rides this *SIMD* default. Thus, the global F_P is set by the maximum routing period determined automatically by *SIMD* based on the *RFA* unless over-ridden by *FPRD* from the *JU* record. The WRAP user can either set $F_P = FPRD$ or adopt the default $F_P =$ future days in maximum routing period. (The maximum routing period includes the current day; F_P does not.) Simulation results can be affected by setting *FPRD* either shorter or longer than the F_P default.

The ***availability forecast period*** (AF_P) for a water right is the number of future days considered in computing the volume of stream flow availability to a water right in Task 1 of Table 3.1. Available flow during days within the simulation forecast period F_P and AF_P may be reduced by the appropriations made by senior rights later in the F_P after the end of the AF_P . The default AF_P automatically computed within *SIMD* based on the *RFA* is the flow travel time from the control point of the water right to the basin outlet. The AF_P thus determined never exceeds and is typically shorter than F_P . The optional input parameter *APRD* in *JU* record field 9 is a maximum limit on the availability forecast period for any and all water rights in the dataset. The optional input parameter *APERIOD* in *DW* record field 2 is a maximum limit on an individual water right. The F_P is adopted and a warning message recorded in the message MSS file if the WRAP user enters a value for *APRD* or *APERIOD* that is greater than F_P .

The ***flood channel capacity forecast period*** for a *FF* record control point is the number of days considered in determining the volume of channel capacity available for releases from the flood control pool of a *FR* record reservoir. The default automatically computed within *SIMD* based on the *RFA* is the travel time from the control point of the *FR* record reservoir to the *FF* record control point. The optional input parameter *CPEARIOD* in *FF* record field 9 is a maximum limit on the channel capacity forecast period. Routing parameters differ between flood flow and normal flow operations. Thus, separate routing factor arrays (*RFAs*) are developed for flood flow and normal flow operations. Simulation of flood control operations is covered in Chapter 5.

A standard listing of the counts of system components is included in the *SIM* or *SIMD* message MSS file for either a monthly or daily simulation. The following additional information is included in the *SIMD* message file for a daily (sub-monthly) simulation.

- largest number of control points forming a continuous stream reach
- number of control points in the dataset with non-zero routing coefficients
- number of routing control points forming a continuous stream reach
- maximum routing period in days for normal flow operations
- maximum routing period in days for flood flow operations
- simulation forecast period

Forecast Simulation Followed by Actual Simulation in Each Time Step

Forecasting in *SIMD* is accomplished through a two phase simulation procedure outlined in Table 3.2 that is repeated for each time step (day) of the hydrologic period-of-analysis. The flow forecasting strategy allows the computational algorithms to look F_P days into the future in determining water availability or remaining channel capacities for the individual rights. The two phase procedure consists of a preliminary simulation covering the maximum forecast period performed solely to develop stream flow availability quantities followed by a one-day actual simulation. The two-simulation flow availability forecast procedure is activated if at least one water right has a forecast period of at least one sub-monthly time step (one day). The forecast simulation covers the maximum F_P specified for any water right. The forecast simulation for the current day incorporates flows forecasted for the actual simulation for the preceding day.

Table 3.2
Forecast Simulation Followed by Actual Simulation

-
1. At the beginning of each time step (day) of the *SIMD* simulation, the daily time step simulation is performed for the simulation forecast period F_P for the sole purpose of forecasting future flow conditions. This forecast simulation starting with the current day uses forecast information developed from the forecast simulation performed for the previous actual day which is now outdated by one day and thus less accurate. The only results saved from the forecast simulation are:
 - array of downstream stream flow availability for each *WR* record water right
 - flood flow capacity array for each flood flow *FF* record control point
 2. The actual daily time step simulation with flow availability array information developed in the forecast simulation described above is performed for the one day.
-

In each day of the multiple-day forecast simulation, water availability is determined considering that day and the latest but now outdated-by-one-day forecast for future days developed for the simulation previously performed for the preceding day. The only results saved are pertinent stream flow availability array and flood flow capacity availability array quantities. These stream flow quantities are approximate in that outdated forecasting is incorporated in their

development. However, these flow quantities allow forecasting to be incorporated into the determination of flow available to each *WR* record water right and *FF* record flood flow capacities in the subsequent one-day actual simulation.

The forecast simulation and subsequent one-day actual simulation are the same except for the following differences.

- The forecast is for multiple days covering the simulation forecast period defined in the preceding section of this chapter. The actual simulation is for one day.
- The forecast simulation uses flow availability array forecasting information which is now outdated by one day. The actual simulation uses the latest updated flow availability array information developed in the forecast simulation to incorporate forecasting in its flow availability determination computations.
- Flood control operations (Chapter 5) are not included in the forecast simulation.

The channel capacity array developed during the forecast simulation for use with flood control *FR/FF* record rights is discussed in Chapter 5. The stream flow availability array developed during the forecast simulation for *WR* record rights contains the minimum amount of downstream future stream flow available to each water right through the forecast period.

As indicated by Table 3.1, in the current time step, as each water right is considered in priority order, Task 1 consists of determining the volume of stream flow that is available to that water right. Without the forecasting option activated, stream flow availability for the current time period is determined from the control point stream flow availability *CPFLOW* array for that day only, considering the control point of the right and other control points located downstream. With the forecasting option activated, the results of downstream water availability determination in the preceding forecast simulation in each of the F_P days is considered in lieu of the values in the *CPFLOW* array which are downstream by a distance of more than one day of travel time.

The forecasting feature may greatly increase simulation computations and computer run times. For example, with a forecast period of ten days, for each day of the simulation, the simulation computations are performed for ten days in the preliminary simulation plus one day in the actual simulation. Thus, the simulation computations are about eleven times greater if the forecasting feature is activated with a ten day forecast period. However, no additional data is recorded in the simulation output files. Recording *SIMD* simulation results in the output file represents a major component of computer run time that is not increased by forecasting.

Reverse Channel Loss Computations and Reverse Routing in the Forecast Simulation

The effects of channel losses and routing are incorporated in the forecast simulation determination of stream flow available to a water right by replicating the loss and routing computations in reverse. Routing and channel loss computations are incorporated in the control point flow availability *CPFLOW* array flow adjustment procedure of Task 4 of Table 3.1. The same routing and channel loss computations, but going backwards in time and direction, are incorporated in the stream flow availability determination of Task 1 of Table 3.1.

Although the monthly *SIM* has no routing or reverse routing, the reverse channel loss computations are included in the monthly *SIM* as well as daily *SIMD*. Flow availability is a linear function of both routing factors and channel loss factors (C_L). With channel losses, the available flow (A) at downstream control points is reduced by the upstream depletion (D) less the channel loss (L), where $L=C_L D$.

$$A_{\text{adjusted}} = A - (D - F_{CL} D) = A - (1.0 - F_{CL}) D \quad (3.8)$$

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 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.

$$A_{\text{adjusted}} = A - [(1.0 - F_{CL1})(1.0 - F_{CL2})(1.0 - F_{CL3}) \dots (1.0 - F_{CLN})] D \quad (3.9)$$

Routing and Forecast Reverse Routing

Reverse routing in the forecast simulation is applied exactly the same with either Muskingum routing or lag and attenuation routing. The following discussion focuses on the lag and attenuation method and associated reverse routing methodology incorporated in the forecast simulation determination of the amount of stream flow available to a water right.

The reverse routing procedure is based on defined time-blocks of flows moving through future days in the forecast simulation. The assessment of water availability in each future day of the forecast simulation is based upon developing factors for each day of the delineated blocks of future days that represent the proportion of the stream flow depletion associated with a water right in the current day that routes to downstream control points in the current and future days. The conceptual basis of the computational methodology is explained as follows.

Routing and associated reverse routing are based on the two parameters LEL and TEL for a control point that delineate the transport of flow changes through the stream reach below the control point as illustrated in Figures 3.1 and 3.2. Referring to the example presented as Figure 3.1 on page 47, the LEL and TEL are 4.5 days and 1.5 days. The LAG entered on the *RT* record is the LEL of 4.5 days. The ATT entered on the *RT* record is 3.0 days (LEL – TEL). The other variables defined below are derived from the parameters LEL and TEL and are illustrated in the examples presented later.

leading edge lag (LEL) – time in days as a real (decimal) number measured from the end of the current day to the point in time at which the downstream (leading) edge of the routed flow change reaches the downstream end of the stream reach (downstream control point). LEL is the lag entered as RPARAMS(cp,1) or RPARAMS(cp,3) in routing *RT* record fields 4 and 6.

trailing edge lag (TEL) – time in days as a real (decimal) number measured from the end of the current day to the point in time at which the upstream (trailing) edge of the routed

flow change reaches the downstream end of the stream reach (downstream control point). $TEL = LEL - ATT$

attenuation (ATT) – time difference between the trailing edge lag (TEL) and leading edge lag (LEL) measured as a real (decimal) number of days. ATT is the attenuation entered as RPARAMS(cp,2) or RPARAMS(cp,4) in routing RT record fields 5 and 7.

leading edge day (LED) – integer number of days after the current day during which the flow change first reaches the downstream end of the routing reach

trailing edge day (TED) – integer number of days after the current day during which the final portion of the flow change reaches the downstream end of the routing reach

spread (S) – attenuation as an integer number of days $S = TED - LED + 1$

cumulative leading edge day (CLED) – summation of LED for multiple reaches in series

cumulative trailing edge day (CTED) – summation of TED for multiple reaches in series

longest forecast period (LFP) – the longest cumulative trailing edge day (CTED) in integer number of days of any sequence of multiple routing reaches in series in the dataset

cumulative spread (CS) – total integer number of days of spread $CS = CTED - CLED + 1$

routing factor array (RFA) – flow change at a control point in each day expressed as a fraction of the total flow change at the control point

A routing factor array (*RFA*) is created at the beginning of a *SIMD* execution, is applied at each time step of the simulation, and does not change during the simulation. The lag and attenuation method and Muskingum method are both linear routing methods that allow creation and application of the *RFA*. The *RFA* can be written to a SMM file for information. The three-dimensional routing factor array *RFA* is indexed as follows.

$$RFA(\textit{routing control point}, \textit{downstream control point}, \textit{day})$$

The routing control point index is sized to include all control points for which routing coefficients are provided in the input file. The downstream control point index is sized to include the maximum number of routing reaches located in series downstream of each routing control point. A routing control point is defined as a control point for which routing parameters are provided in the input file. A routing reach is the stream reach between a routing control point and its downstream control point which is either another routing control point or the outlet.

The *RFA* day index is dimensioned to include the number of days in the longest forecast period (*LFP*). *SIMD* will automatically determine the path with the maximum cumulative trailing edge day (*CTED*). The forecast period extends from day 1 after the current day to this longest forecast period (*LFP*) representing the maximum *CTED* in the dataset. Extending the forecast simulation past the maximum *CTED* increases the computations with no effect on simulation results except for improvements in the forecasts incorporated in the forecast simulation discussed later. Shortening the forecast simulation can affect simulation results by not fully protecting senior rights from earlier actions of junior rights.

The routed flow changes consist of either stream flow depletions, return flows, or a reservoir release. Flow changes can be modified by both channel losses and routing. The flow changes serve to adjust the *CPFLOW* array for all control points located downstream of the water right action causing the flow change.

Reverse routing combined with reverse channel loss computations determines equivalent quantities in the current day at an upstream control point that would occur, as a result of forward routing and channel losses, in the future flows at downstream control points reflected in the *CPFLOW* available flow array. The maximum flow amount available to the water right of concern is the minimum of relevant *reverse routed* and current day *CPFLOW* quantities.

The amount of stream flow available to a water right in the current day is the minimum of the available flow at the control point of the water right and quantities at downstream control points obtained by combining the *CPFLOW* and *RFA* arrays. *CPFLOW* array quantities are divided by the corresponding *RFA* quantities. Only cells with non-zero values in the *RFA* are considered. The cells are further limited by *ADJINC* option 6 (*JD* record field 8) to consider only downstream control points affected by senior water rights. Channel loss adjustments are also reversed. As discussed later, forecasting is incorporated in the forecast simulation.

Routing and Reverse Routing Examples

The reverse routing and reverse channel loss computations are coded in *SIMD* from the perspective of integrating these computations into the overall simulation. The following examples illustrate the basic concepts of the reverse routing and reverse channel loss computational methodology without addressing the details of the computer code.

The lag and attenuation routing methodology and associated creation of a routing factor array (*RFA*) are illustrated by Examples 1, 2, and 3 on the following pages. A *RFA* can be similarly created with the *SIMD* adaptation of the Muskingum routing method. Though a 900 acre-feet stream flow change is selected for the examples, the identically same *RFA* is created with any other stream flow change. The *RFA* contains fractions of the total change (summing to 1.0), which are the same regardless of the amount of the total change to flow.

Example 4 is an extension of Example 3 illustrating the combining of channel loss factors and routing factors. In forecasting flow availability for a water right in Example 4, volumes from the *CPFLOW* array are divided by both deliver factors and routing factors. Though conceptually the same, the computations are organized differently in *SIMD*. Loss and routing computations are separated and do not necessarily have to include the same control points. The channel loss computations are performed in *SIMD* before the routing computations.

Routing and Reverse Routing Example 1

A streamflow depletion of 900 acre-feet in day zero at control point CP-1 is routed to control points CP-2, CP-3, CP-4, and CP-5 located in series downstream. In these examples, the routing parameters LEL and TEL are the same for the four reaches, though in general they will typically vary between reaches. The computed *RFA* array represents the fraction of the 900 acre-feet (or any other amount) in day zero that reaches the specified control points in each day.

Leading Edge Lag (LEL)	1.0 day	1.0 day	1.0 day	1.0 day	
Trailing Edge Lag (TEL)	3.0 days	3.0 days	3.0 days	3.0 days	
Attenuation (TEL-LEL)	2.0 days	2.0 days	2.0 days	2.0 days	
Leading Edge Day (LED)	1	1	1	1	
Trailing Edge Day (TED)	3	3	3	3	
Spread (S)	3 days	3 days	3 days	3 days	
Cumulative Leading Edge Day	1	2	3	4	
Cumulative Trailing Edge Day	3	6	9	12	
Cumulative Spread (CS)	3 days	5 days	7 days	9 days	
Forward Routing					
	Flow Volume (acre-feet) at Control Point				
Day	CP-1	CP-2	CP-3	CP-4	CP-5
0	900				
1		300			
2		300	100		
3		300	100+100=200	33	
4			100+100+100=300	33+67=100	11
5			100+100=200	33+67+100=200	11+33=44
6			100	67+100+67=233	11+33+67=111
7				100+67+33=200	33+67+77=178
8				67+33=100	67+77+67=211
9				33	77+67+33=178
10					67+33+11=111
11					33+11=44
12					11
Routing Factor Array (RFA) Developed for Forecasting Reverse Routing					
	Flow Volume as a Fraction of Total at Control Point				
Day	CP-1	CP-2	CP-3	CP-4	CP-5
0	1.00000				
1		0.33333			
2		0.33333	0.11111		
3		0.33333	0.22222	0.03704	
4			0.33333	0.11111	0.01235
5			0.22222	0.22222	0.04938
6			0.11111	0.25926	0.12345
7				0.22222	0.19753
8				0.11111	0.23456
9				0.03704	0.19753
10					0.12345
11					0.04938
12					0.01235

Routing and Reverse Routing Example 2

Example 2 is identical to Example 1 except the parameters LEL and TEL are shorter. With LEL of zero, the spread extends back to day zero.

Leading Edge Lag (LEL)	0.0 day	0.0 day	0.0 day	0.0 day	
Trailing Edge Lag (TEL)	2.0 days	2.0 days	2.0 days	2.0 days	
Attenuation (TEL-LEL)	2.0 days	2.0 days	2.0 days	2.0 days	
Leading Edge Day (LED)	0	0	0	0	
Trailing Edge Day (TED)	2	2	2	2	
Spread (S)	3 days	3 days	3 days	3 days	
Cumulative Leading Edge Day	0	0	0	0	
Cumulative Trailing Edge Day	2	4	6	8	
Cumulative Spread (CS)	3 days	5 days	7 days	9 days	
Forward Routing					
	Flow Volume (acre-feet) at Control Point				
Day	CP-1	CP-2	CP-3	CP-4	CP-5
0	900	300	100	33	11
1		300	100+100=200	33+67=100	11+33=44
2		300	100+100+100=300	33+67+100=200	11+33+67=111
3			100+100=200	67+100+67=233	33+67+77=178
4			100	100+67+33=200	67+77+67=211
5				67+33=100	77+67+33=178
6				33	67+33+11=111
7					33+11=44
8					11
Routing Factor Array (RFA) Developed for Forecasting Reverse Routing					
	Flow Volume as a Fraction of Total at Control Point				
Day	CP-1	CP-2	CP-3	CP-4	CP-5
0	1.00000	0.33333	0.11111	0.03704	0.01235
1		0.33333	0.22222	0.11111	0.04938
2		0.33333	0.33333	0.22222	0.12345
3			0.22222	0.25926	0.19753
4			0.11111	0.22222	0.23456
5				0.11111	0.19753
6				0.03704	0.12345
7					0.04938
8					0.01235

A streamflow depletion of 900 acre-feet in day zero at control point CP-1 is routed to control points CP-2, CP-3, CP-4, and CP-5 in the three examples. Though developed using a streamflow depletion of 900 acre-feet, the routing factor arrays (*RFAs*) developed in these examples will be the same for any other streamflow depletion amount at control point CP-1 in day zero. The *RFA* represents the fraction of the day-zero stream flow depletion that reaches the specified control points in each day. Reverse routing is based on dividing quantities from the flow availability *CPFLOW* array by the corresponding quantities from the *RFA*.

Routing and Reverse Routing Example 3

Unlike Examples 1 and 2, in Example 3, the routing parameters LEL and TEL are fractional numbers. LEL is 1.75 days and TEL is 3.25 days.

Leading Edge Lag (LEL)	1.75 days	1.75 days	1.75 days	1.75 days	
Trailing Edge Lag (TEL)	3.25 days	3.25 days	3.25 days	3.25 days	
Attenuation (TEL-LEL)	1.5 days	1.5 days	1.5 days	1.5 days	
Leading Edge Day (LED)	1	1	1	1	
Trailing Edge Day (TED)	3	3	3	3	
Spread (S)	3 days	3 days	3 days	3 days	
Cumulative Leading Edge Day	1	2	3	4	
Cumulative Trailing Edge Day	3	6	9	12	
Cumulative Spread (CS)	3 days	5 days	7 days	9 days	
<u>Forward Routing</u>					
	Flow Volume (acre-feet) at Control Point				
Day	CP-1	CP-2	CP-3	CP-4	CP-5
0	900				
1		150			
2		600	25		
3		150	100+100=200	4.17	
4			25+400+25=450	16.67+33.33=50.0	0.69
5			100+100=200	4.17+133.3+75=212.5	2.78+8.33=11.1
6			25	33.3+300+33.3=366.7	0.69+33.3+35.4=69.4
7				75+133.3+4.17=212.5	8.33+141.7+61.1=211.1
8				33.3+16.67=50.0	35.4+244.5+35.4=315.3
9				4.17	61.1+141.7+8.3=211.1
10					35.4+33.3+0.69=69.4
11					8.3+2.78=11.1
12					0.69
<u>Routing Factor Array (RFA) Developed for Forecasting Reverse Routing</u>					
	Flow Volume as a Fraction of Total at Control Point				
Day	CP-1	CP-2	CP-3	CP-4	CP-5
0	1.00000				
1		0.16667			
2		0.66667	0.02778		
3		0.16667	0.22222	0.00463	
4			0.50000	0.05556	0.00077
5			0.22222	0.23611	0.01235
6			0.02778	0.40741	0.07716
7				0.23611	0.23456
8				0.05556	0.35033
9				0.00463	0.23456
10					0.07716
11					0.01235
12					0.00077

Creation of RFA values may result in extremely small quantities being distributed at the leading and trailing edges of the routed flow change. Input parameters RFALIM(cp,1) and

RFALIM(cp,2) in fields 9 and 10 of the *RT* record are used to eliminate small quantities from the leading and trailing edges of the routing for normal and flood control routing, respectively. RFALIM is entered on the *RT* record as a decimal value between 0.0 and 1.0 representing percentages between 0% and 100%. RFALIM is applied as follows. The *RFA* values at a control point are accumulated. Days where the cumulative *RFA* value is less than RFALIM on the leading edge are changed to zero. Days where the cumulative *RFA* value is greater than 1.0 minus RFALIM on the trailing edge are set to zero. The *RFA* values that remain after zeroing any leading and trailing edge days are adjusted proportionally so that the remaining *RFA* values cumulatively equal 1.0.

RFALIM is only applicable to the stream reach below the control point identified as RTID in *RT* record field 2. RFALIM is by default set to 0.10 or 10.0% for all normal flow routing reaches. The default for all flood control routing is 0.20 or 20.0%. For realistic values in the *RFA*, parameters for RFALIM should not be chosen that increase in downstream reaches. Increasing RFALIM in downstream reaches effectively represents decreasing attenuation as flow changes are propagated downstream. Routing should always result in the same or greater days of cumulative spread as flows propagate downstream.

Example 4 on the next page is a modified version of Example 3. Application of the default 10.0% limit for normal flow routing is shown in the Example 4 routed flow change and *RFA* array. The leading and trailing edges of the routed flow for *RFA* values at CP-3, CP-4, and CP-5 are below the 10.0% limit on a cumulative basis. *RFA* value of 0.16667 for day 1 at CP-1 is greater than 10%. The cumulative *RFA* value for the start of day 3 at CP-1 is 0.83337 which is less than 1.0 minus RFALIM or 0.90. Therefore, no *RFA* values at CP-1 will result in routed volumes that are below the 10.0% limit.

Days 2 and 6 at CP-3, days 4 and 8 at CP-4, and days 5, 6, 10, and 11 at CP-5 are less than the cumulative limit of 10.0%. The *RFA* values for these days are set to zero in Example 4. The *RFA* values remaining at CP-3, CP-4, and CP-5 are increased proportionally so that the cumulative *RFA* values at each control point equal 1.0.

The routed flow volumes in Example 4 are similarly adjusted for the 10.0% limit. Thus, the routed flows in any day are always greater than 10.0% of 900 acre-feet, which is 90.0 acre-feet. Zeroing small *RFA* values on the leading and trailing edges of the routed flow change will also reduce the cumulative spread. For example and prior to application of the 10.0% limit, the routed flow at CP-5 had a cumulative spread of 9 days. The first and last days of the routed flow had an extremely low volume of less than 1.0 acre-feet. Days 7, 8, and 9 prior to the application of the 10.0% limit were responsible for 82% of the routed flow at CP-5. After application of the 10.0% limit to the leading and trailing edges of the routing at CP-5, days 7, 8, and 9 are the only days represented in the routed flow at CP-5. Cumulative spread is reduced from 9 to 3 days.

The *RFA* array is constructed and the limit RFALIM is applied prior to consideration of channel losses. Prior to the consideration of channel losses, the *RFA* values are adjusted such that the summation of values is equal to 1.0. After consideration of channel losses, the summation of values in the *RFA* will equal 1.0 multiplied by the cumulative delivery factor between the control point where the flow change was made and the downstream control point.

Routing and Reverse Routing Example 4

Example 4 is a modified version of Example 3 that incorporates RFA Limits with the parameters RFALIM(cp,1) and RFALIM(cp,2).

Leading Edge Lag (LEL)	1.75 days	1.75 days	1.75 days	1.75 days	
Trailing Edge Lag (TEL)	3.25 days	3.25 days	3.25 days	3.25 days	
Attenuation (TEL-LEL)	1.5 days	1.5 days	1.5 days	1.5 days	
Leading Edge Day (LED)	1	1	1	1	
Trailing Edge Day (TED)	3	3	3	3	
Spread (S)	3 days	3 days	3 days	3 days	
Cumulative Leading Edge Day	1	3	5	7	
Cumulative Trailing Edge Day	3	5	7	9	
Cumulative Spread (CS)	3 days	3 days	3 days	3 days	
<u>Forward Routing</u>					
Flow Volume (acre-feet) at Control Point					
Day	CP-1	CP-2	CP-3	CP-4	CP-5
0	900				
1		150			
2		600	0		
3		150	211.8		
4			476.4	0	0
5			211.8	241.6	0
6			0	416.8	0
7				241.6	257.6
8				0	384.8
9					257.6
10					0
11					0
12					0
<u>Routing Factor Array (RFA) Developed for Forecasting Reverse Routing</u>					
Flow Volume as a Fraction of Total at Control Point					
Day	CP-1	CP-2	CP-3	CP-4	CP-5
0	1.00000				
1		0.16667			
2		0.66667	0		
3		0.16667	0.23529		
4			0.52941	0	0
5			0.23529	0.26842	0
6			0	0.46316	0
7				0.26842	0.28624
8				0	0.42752
9					0.28624
10					0
11					0
12					0

Example 5 which Incorporates Channel Losses into Example 4

The channel loss factors (C_L) entered on *CP* records and corresponding delivery ratios are as follows for the four reaches of Example 4. The reverse channel loss computations are performed separately from the routing factor array *RFA* in *SIMD*. However, channel loss and routing effects are combined in the same factors in this illustrative example. The routing factors of Example 4 are multiplied by the cumulative delivery factors with the following results.

Stream Reach	Channel Loss Factor	Delivery Factor	Cumulative Delivery Factor
CP-1 to CP-2	0.20	0.80	0.80
CP-2 to CP-3	0.15	0.85	0.68
CP-3 to CP-4	0.25	0.75	0.51
CP-4 to CP-5	0.10	0.90	0.459

Day	Delivery Ratio x Routing Factor				
	CP-1	CP-2	CP-3	CP-4	CP-5
		DR = 0.80	DR = 0.68	DR = 0.51	DR = 0.459
0	1.00000				
1		0.13334			
2		0.53334			
3		0.13334	0.16000		
4			0.36000		
5			0.16000	0.13689	
6				0.23621	
7				0.13689	0.13138
8					0.19623
9					0.13138

The combined routing/loss factor array tabulated in the table above is interpreted as follows. A stream flow depletion in Day 0 at control point CP-1 of 1.0 acre-foot results in adjustments in the *CPFLOW* flow availability array in the amounts in acre-feet shown in the table above at control points CP-2, CP-3, CP-4, and CP-5 in Days 1, 2, 3, 4, 5, 6, 7, 8, and 9. Conversely, amounts in the *CPFLOW* array are divided by the fractions in the table above to determine water availability at CP-1 in Day 0. The volume of flow available at CP-1 in Day 0 is the minimum of the *CPFLOW* flow in Day 0 at CP-1 and each of the elements of the array of the *CPFLOW* flows divided by *RFA* elements for the 9 future days at CP-2, CP-3, CP-4, and CP-5. Thus, the volume of flow available at CP-1 in Day 0 is the minimum of the 13 numbers computed by dividing *CPFLOW* array available flows by the numbers in the table above.

The recommended *JD* record field 8 *ADJINC* option 7 is to limit the downstream control points considered in computing flow availability for a right to those control points at which senior water rights are located. In the example, senior rights may be located at all of the control points CP-2, CP-3, CP-4, and CP-5. However, if not, only the factors at the pertinent downstream control points are applied in determining the amount of stream flow available to the water right at control point CP-1.

CPFLOW array quantities are divided by the fractions in the combined channel loss and routing factor array table on the preceding page in the determination of flow availability. An alternative way of viewing the combined routing and loss factor array table is to take the reciprocals of the fractions in the above table to obtain the following table. The following version of the table is applied as follows to determine the amount of water available in Day 0 at control point CP-1. Volume amounts from the *CPFLOW* array are multiplied by the numbers in the array shown below and the minimum of the products is selected. The available flow is the minimum of the *CPFLOW* flow in Day 0 at CP-1 and these 12 products (13 flows).

Day	Multiplier Factors				
	CP-1	CP-2	CP-3	CP-4	CP-5
0	1.00000				
1		7.500			
2		1.875			
3		7.500	6.250		
4			2.778		
5			6.250	7.305	
6				4.234	
7				7.305	7.611
8					5.096
9					7.611

Forecasting in the Forecast Simulation

The forecasted flows for the days covered by the maximum F_P are carried forward to the forecast simulation. The following example illustrates the incorporation of forecasting in the forecast simulation. The longest routing period is 5 future days according to the RFA presented below. This example uses a forecast period of 5 future days and covers a water right located at control point A and downstream to the outlet through control points B, C, D, and E. The values in the RFA represent the combination of routing factors and delivery factors from control point A to the downstream control points in futures days. For example, value b_i represents the combination of delivery and routing factor from control point A to control point B one day beyond the current period. Flow at control point B, measured at the priority of the water right at control point A, one day into the future is divided by factor b_i to determine if it represents a constraint to water availability for the water right at control point A in the current period.

Table 3.3
Example Routing Factor Array (RFA) Values

Day	Delivery Ratio x Routing Factor				
	CP-A	CP-B	CP-C	CP-D	CP-E
0	$a_0 = 1.00$	b_0			
i		b_i	c_i		
ii			c_{ii}	d_{ii}	
iii			c_{iii}	d_{iii}	e_{iii}
iv				d_{iv}	e_{iv}
v					e_v

Table 3.4 represents flows at control points A through E as measured at the priority of the water right at control point A, hereafter referred to as WR-A, in each day of the final simulation and forecast simulation. The downstream flows pertinent to determining water availability WR-A are listed on horizontal rows. In the first forecast simulation, no future downstream flows have been observed. Therefore, only the priority order of the *CPFLOW* array values at control points A and B determines the water availability for WR-A. However, as the forecast simulation progresses through days 2 through 6, the future priority order values of the *CPFLOW* array at control points B, C, D, and E become accessible for the water availability computation relevant for day 1 at control point A.

The horizontal row for the final real simulation for day 1 is interpreted as follows. The value of *CPFLOW* observed at each control point at the priority of WR-A is designated by the control point letter and the Arabic numeral of the day in the forecast simulation. B2 represents the *CPFLOW* value at control point B on forecast day 2 at the priority of WR-A. B2 is reverse routed by RFA value b_i . The subscript Roman numerals on b_i indicate the number of future days relative to the current day. The *CPFLOW* value at control point A is not shown as being divided by a RFA value because the divisor a_0 will always be equal to 1.00. In addition to the *CPFLOW* value at control point A, the *CPFLOW* value at B on day 1 is also a present day consideration. However, the value of B1 is divided by RFA value b_0 that is less than 1.00. Water availabilities for WR-A on days 1, 2, and 3 of the final simulation are computed as:

$$\text{Final Day 1 Availability} = \text{Minimum}(A1, B1/b_0, B2/b_i, C2/c_i, C3/c_{ii}, \dots, D5/d_{iv}, E5/e_{iv}, E6/e_v)$$

$$\text{Final Day 2 Availability} = \text{Minimum}(A2, B2/b_0, B3/b_i, C3/c_i, C4/c_{ii}, \dots, D6/d_{iv}, E6/e_{iv}, E7/e_v)$$

$$\text{Final Day 3 Availability} = \text{Minimum}(A3, B3/b_0, B4/b_i, C4/c_i, C5/c_{ii}, \dots, D7/d_{iv}, E7/e_{iv}, E8/e_v)$$

If the RFA values in Table 3.3 for downstream control points contained zeroes for all downstream control points on day 1 of the future, expressed in the table by Roman numeral i , the only current day constraint on WR-A water availability is the *CPFLOW* value at A. Since RFA value b_0 is non-zero in this example, current day *CPFLOW* at control point B is always considered with reverse routing along with current day *CPFLOW* at control point A.

In the first forecast simulation, there are no previous forecast data for future downstream control point flows. The first forecast simulation only considers flows at control point A and B divided by RFA values a_0 and b_0 , respectively, for determining water availability. However, as each day of the forecast progresses, the *CPFLOW* values at control points B through E become known quantities and are evaluated as minimum water availability constraints for the final simulation of day 1 and also for days 2 through 5 for the next forecast simulation. For example, when the first forecast simulation reaches day 6, *CPFLOW* values at control points B through E can be evaluated as minimum water availability constraints for the final simulation of day 1 and for days 2 through 5 of the second forecast simulation. The first forecast simulation ends on day 6. The second forecast simulation covers days 2 through 7. No future downstream *CPFLOW* data exists for days 6 and 7 of the second forecast simulation because the first forecast simulation terminated at the conclusion of forecast day 6.

Table 3.4
Diagram of Control Point Flows for the Forecast and Final Simulations

	Day	1	2	3	4	5	6	7	8	9
Current = Day 1										
Forecast	1	A1,B1								
	2		A2,B2							
	3			A3,B3						
	4				A4,B4					
	5					A5,B5				
	6						A6,A6			
Final Real Simulation	1	A1,B1	B2,C2	B3,C3,D3	C4,D4,E4	D5,E5	E6			
Current = Day 2										
Forecast	2		A2,B2	<i>B3,C3</i>	<i>C4,D4</i>	<i>C5,D5,E5</i>	<i>D6,E6</i>			
	3			A3,B3	<i>B4,C4</i>	<i>C5,D5</i>	<i>C6,D6,E6</i>			
	4				A4,B4	<i>B5,C5</i>	<i>C6,D6</i>			
	5					A5,B5	<i>B6,C6</i>			
	6						A6,B6			
	7							A7,B7		
Final Real Simulation	2		A2,B2	B3,C3	B4,C4,D4	C5,D5,E5	D6,E6	E7		
Current = Day 3										
Forecast	3			A3,B3	<i>B4,C4</i>	<i>C5,D5</i>	<i>C6,D6,E6</i>	<i>D7,E7</i>		
	4				A4,B4	<i>B5,C5</i>	<i>C6,D6</i>	<i>C7,D7,E7</i>		
	5					A5,B5	<i>B6,C6</i>	<i>C7,D7</i>		
	6						A6,B6	<i>B7,C7</i>		
	7							A7,B7		
	8								A8,B8	
Final Real Simulation	3			A3,B3	B4,C4	B5,C5,D5	C6,D6,E6	D7,E7	E8	
Current = Day 4										
Forecast	4				A4,B4	<i>B5,C5</i>	<i>C6,D6</i>	<i>C7,D7,E7</i>	<i>D8,E8</i>	
	5					A5,B5	<i>B6,C6</i>	<i>C7,D7</i>	<i>C8,D8,E8</i>	
	6						A6,B6	<i>B7,C7</i>	<i>C8,D8</i>	
	7							A7,B7	<i>B8,C8</i>	
	8								A8,B8	
	9									A9,B8
Final Real Simulation	4				A4,B4	B5,C5	B6,C6,D6	C7,D7,E7	D8,E8	E9

CPFLOW values from the previous forecast simulation are shown in Table 3.4 as italicized letters with their corresponding observation date in Arabic numerals. *CPFLOW* values at control point A and B for the current day of the forecast are not italicized because these values are current day flows during the forecast simulation. The *CPFLOW* value at control point B from the current day and the future flow at B from the previous forecast are considered as water

availability constraints. The bold letters used on the row for each final day simulation represent flows that are observed on the day of the final simulation at control point A and B, and future flows at control points B through E from the forecast simulation that just completed. These bold letter future flows at control points B through E form the basis of the water availability forecast for the next forecast simulation.

Italicized letters indicate future *CPFLOW* values measured in the previous forecast simulation. These measurements are one day old, but represent the best estimate of future downstream *CPFLOW* at the priority of WR-A. Non-italicized letters indicate *CPFLOW* values measured in the current day. Water availability for WR-A on days 2, 3, and 4 within the second forecast simulation are computed as follows.

$$\text{Forecast Day 2 Availability} = \text{Minimum}(A2, B2/b_0, B3/b_i, C3/c_i, C4/c_{ii}, \dots, D6/d_{iv}, E6/e_{iv}, E7/e_v)$$

$$\text{Forecast Day 3 Availability} = \text{Minimum}(A3, B3/b_0, B4/b_i, C4/c_i, C5/c_{ii}, \dots, D7/d_{iv}, E7/e_{iv}, E8/e_v)$$

$$\text{Forecast Day 4 Availability} = \text{Minimum}(A4, B4/b_0, B5/b_i, C5/c_i, C6/c_{ii}, \dots, D8/d_{iv}, E8/e_{iv}, E9/e_v)$$

Length of the Forecast Period

Each forecast simulation uses the downstream future *CPFLOW* values from the previous forecast simulation. The diagram of *CPFLOW* values shown in Table 3.4 is for a simulation with a forecast period equal to the routing period from the water right location at control point A to the last control point E. In the second forecast simulation of Table 3.4, no future flows at control points B through E are available from the previous forecast for days 7 or 8. Computation of water availability for WR-A on forecast days 6 and 7 is only based on *CPFLOW* at A and B.

The last two days of each forecast simulation will always be without downstream future flow observations from the previous 1 day old forecast simulation. If the forecast simulation is equal to the longest routing period in the basin, then water rights located at control points with the longest routing period will never have future downstream flows available for the last two days of the forecast simulation. The final real simulation of the current day will have access to future downstream flows covering all days of the routing period to the outlet. However, the last two forecast days of *CPFLOW* data will be obtained from a forecast simulation in which some water rights did not fully forecast senior downstream stream flow needs.

SIMD automatically sets the forecast simulation period to twice the longest routing period when *JU* record field 8 is left blank. This ensures that every water right is simulated during the forecast with future downstream flows for each forecast day that covers the current forecast day with enough future days from the previous forecast simulation to provide downstream future flows at the relevant control points all the way to the outlet. In the example from Tables 3.3 and 3.4, the routing period to the outlet is the current day plus 5 future days. The default *SIMD* forecast simulation will cover 12 days, of which 11 are future days.

Using a double future routing period to set the forecast simulation period, WR-A in the second forecast simulation in the example illustrated in Table 3.4 will be simulated in day 7 of the forecast with downstream *CPFLOW* values at control points B through E from the previous forecast simulation covering days 8 through 12. Recall that the second forecast simulation

beings on day 2 and the routing period to the outlet is 5 future days. The forecast simulation period is set equal to 12 days which is equal to the 5 day future days plus the current period times 2. Days 8 through 13 of the second forecast simulation will not have all possible downstream future flows to the outlet. When the second forecast simulation reaches days 12 and 13, the only flow for determining water availability will be current day flows at control point A and B. Days 8 through 13 of the second forecast simulation are necessary, however, to provide a complete set of downstream future flows for days 3 through 9 of the third forecast simulation.

Adjustment of Future Downstream Flow

Downstream values of *CPFLOW* are considered at the priority of each water right during the forecast simulation. Each downstream *CPFLOW* value is evaluated as a possible constraint on upstream water availability for the final simulation of the current real day. Downstream *CPLFLOW* values are not considered if the control point *RFA* value is zero for the relevant future day in the forecast. The number of days between the current real day and the forecast day determines which *RFA* value is used for reverse routing of the *CPFLOW* value. Each downstream *CPFLOW* value is also evaluated as a possible constraint on water availability for days within the next forecast simulation.

In the example illustrated in Table 3.4, the value of *CPFLOW* at control point D on day 5 of the first forecast simulation is evaluated as a possible water availability constraint for WR-A in the final simulation of real day 1. Flow D5 from the first forecast simulation is also evaluated as a possible water availability constraint for forecast days 2 and 3 of the second forecast simulation. The italicized *D5* in the rows for days 2 and 3 of the second forecast simulation indicate that *D5* was measured in the first forecast simulation.

Each forecast day simulates all water rights in priority order in the same manner as the final simulation of the real current day. Water rights in the forecast make depletions, storage releases, refill storage, and generate returns according to the same rules used in the final real day simulation. As junior rights are simulated through the forecast, their priority order considerations of downstream *CPFLOW* values will be reflective of all senior right actions up to their respective step in the priority sequence.

If *WRMETH* option 1 is selected with *JU* record field 5 or if *WRFCST* option 1 is selected with *JU* record field 6, the observations of *CPFLOW* at downstream control points will also be reflective of junior actions from either the previous real final day simulation or prior days within the forecast simulation. Past junior actions were made with forecasted knowledge of downstream future flow limitations at their respective priority. Past junior actions are therefore limited according to priority based forecasts of downstream flows in the present and forecast days. To the extent prior forecasts correctly estimated downstream future flow limitations, past junior actions should not reduce water availability for present and future senior water rights.

Selecting *WRMETH* option 1 and *WRFCST* option 2 will prevent actions of junior rights during the forecast simulation from affecting the consideration of future downstream values of *CPFLOW* by senior water rights. Senior rights will be able to make changes to flow in the final simulation of the current real day according to availability based on the present value of

CPFLOW at their diversion location and future downstream values of *CPFLOW* that contain no effects of future junior actions.

In the example illustrated in Table 3.4 and assuming *WRFCST* option 1 is selected, the value of *CPFLOW* at control point D on day 5 of the first forecast simulation will reflect all water right actions on days 1, 2, 3, 4 and only senior water right actions on day 5 up to the priority order of WR-A. Flow D5 is evaluated as a possible water availability constraint for the final simulation of real day 1. However, flow D5 has been altered by depletions from WR-A that were made in forecast days 1, 2, and 3 and routed downstream to control point D with factors from the RFA. If flow D5 is to be evaluated as a constraint against WR-A's water availability in final day 1, the water right's own depletions made in forecast days 1, 2, and 3 are used to adjust the value of D5. The only relevant constraints to WR-A's water availability for final real day 1 are those senior water right needs in days 1 through 5. Junior water right depletions in days 1 through 4 may potentially be reflected in flow D5. However, junior right depletions are made within the forecast simulation when future senior effects are first considered. These future senior effects also include the depletions and returns of WR-A as represented in the *CPFLOW* values at control points A through E.

The same adjustment at control point D for WR-A's own depletions in forecast days 1, 2, and 3 is made when *WRFCST* option 2 is selected. The difference with the selection of option 2 is that it eliminates the possibility of any junior action within the forecast simulation from affecting *CPFLOW*.

Adjustment to future downstream *CPFLOW* values removes the potential for a water right's own depletions to constrain its availability in the final real day simulation. The adjustment is only made for the forecast simulation depletions by the water right under consideration. WR-A's future downstream availability is constrained by future senior needs, but not future effects of WR-A on downstream flows. WR-A's depletions are not adjusted when considering other water rights as the priority sequence progresses. Water rights junior to WR-A will limit their water availability according to all changes made to *CPFLOW* by WR-A.

Adjustments to downstream *CPFLOW* values during the forecast simulation are made for each water right under consideration in the following manner. On the each day beyond the first day the forecast simulation, a water right's own depletions in all previous days of the forecast are known. The amount of routed depletion from the water right that is represented at the downstream control point is added back to the value of *CPFLOW*. The adjustment is only applied when evaluating the *CPFLOW* values relevant to the water availability computation for the final real day. In Table 3.4, only the bold letter values of *CPFLOW* are adjusted for routed depletions from WR-A which occurred during the forecast simulation.

In the example illustrated in Table 3.4, the value of *CPFLOW* at control point D on day 5 of the first forecast simulation will reflect all of WR-A's actions from forecast days 1, 2, and 3. No portion of the depletion by WR-A on day 4 has arrived at control point D on day 5. Flow D5 will be evaluated as a constraint on water availability in the final simulation of real day 1, and as a constraint on water availability in the second forecast simulation of day 2 and 3. Before evaluating flow D5 as a constraint on water availability for final day 1, D5 is adjusted for the

portion of the depletion that has arrived from days 1, 2, and 3 of the first forecast simulation at control point D.

Adjustment of *CPFLOW* values is not performed for determining water availability for days within the next forecast simulation. When evaluating flow D5 in the first forecast simulation as a potential constraint on water availability for day 2 of the second forecast simulation, D5 is not adjusted for the portion of the depletion that has arrived from days 2 and 3 of the first forecast simulation at control point D. Forecasted *CPFLOW* values to be used within the next forecast simulation are only estimates of flows from a 1 day old simulation. Each day the forecast simulation is performed again and forecast information for the next forecast simulation is updated. Selecting *WRFCST* option 2 may improve the estimate of forecasted *CPFLOW* to be used within the next forecast simulation by eliminating the possibility for impacts by future junior actions.

A water right's own routed depletions from the forecast simulation are added back to the downstream future *CPFLOW* values as an adjustment for computing water availability for the final real day. This removes the potential for a water right's own depletion on the current day of the forecast and possibly future days in the forecast from limiting the water availability computation in the final real day. A water right's own routed return flows during the forecast simulation are not subtracted from downstream future *CPFLOW* values. Return flows can be added to the basin at any control point and optionally delayed a time step. Alternatively, return flows can be modeled with constant inflow *CI* records and have no computational connection to the underlying water right *WR* record. A water right's own future return flows are a part of the available stream flow as are any inflow source in the simulation. By not subtracting the routed return flows from the forecast simulation, the computation of water availability for the final real day allows a water right to rely on its own return flows as a source of stream flow to meet future downstream senior water right needs.

Applications of Flow Forecasting

Forecasting of future river flows may be considered from the dual perspectives of actual forecasts in the real world and computational forecasts in the *SIMD* model. Forecasting can also be viewed from the dual perspectives of water supply and flood control. Forecasting in *SIMD* serves two purposes.

1. Prevention of junior rights from making depletions of stream flow in the current day which will otherwise be appropriated by senior water rights in future time steps.
2. Prevention of flows at downstream locations exceeding specified allowable limits either by engaging flood control storage filling or by modulating flood control storage releases.

Flood control reservoir operations are discussed in Chapter 5. From a water supply perspective, the sole purpose of forecasting in *SIMD* is to protect senior rights from having their water taken by other rights with junior priorities. The concern is that an appropriation by a junior right could affect senior rights one or more days into the future. Forecasting allows limiting the amount of water available to the upstream junior right.

With *WRMETH* option 2, stream flow depletions made from the non-forecast simulation for each right are routed within the priority sequence, thus protecting senior rights from earlier actions of junior rights. However, option 2 increases the probability for *double-taking* of the same water where seniors appropriate flows that have already been incorrectly appropriated by juniors in previous days. *WRMETH* option 1 is much less likely to result in *double-taking* because all past water right changes to flow are applied to the *CPFLOW* array before new changes to flow are made in the current day. *WRFCST* option 2 provides senior rights future downstream *CPFLOW* values that are not affected by future junior water right actions. Combining *WRMETH* option 1 with *WRFCST* option 2 may produce simulation results that optimally minimize routing adjustments while maximizing water availability for senior rights.

Flow forecasting is approximate in the real-world. Forecasting capabilities as well as monitoring and other aspects of water right permit administration are not precise. Water users are legally obligated to curtail diversions and pass inflows through their reservoirs as necessary to accommodate senior rights. However, permit administration and other aspects of priority order water management are imperfect in practice. Forecasting of stream flow availability over several days into the future is highly uncertain in reality.

Flow forecasting within *SIMD*, like in the real-world, is imperfect. The use of real-world stream flow patterns to represent daily flows throughout the basin necessitates the use of routing parameters to propagate changes to stream flow downstream. The *SIMD* forecasting methodology is based on the input routing parameters, which are approximate. The *RFA* array is used in the forecasting methodology to determine water availability through reverse routing of future downstream flows and also to automatically assign forecast periods. The validity of routing parameters will affect the performance of flow forecasting. However, even with carefully calibrated routing parameters, real-world and simulated stream flow patterns contain events that do not perfectly match with the characteristics of the calibrated parameters. Therefore, imperfections in forecasts of stream flow will exist when determining downstream future flow conditions. The forecast simulation is repeated and entirely updated after each final simulation of the current time step in order to correct and minimize imperfections.

Real-world stream flow forecasting is often associated with another aspect of water supply operations that is not directly addressed in *SIMD*. Water supply diversions may be pumped from a river at sites located several days travel time below dams from which the water is released. A diversion today diverts water released from the reservoir several days ago combined with unregulated flows. Water managers may try to set releases based on forecasting unregulated flows entering the river between the dam and diversion sites and the attenuation and channel losses associated with the reservoir release. *SIMD* does not apply forecasting in this sense.

SIM and *SIMD* allow diversions to be met by combinations of unregulated river flows and/or releases from one or more reservoirs located any distance upstream with any combination of travel times to the downstream point of diversion. Channel loss computations are applied to the reservoir releases to determine their contribution to regulated flows at control points between the dam and diversion site. Releases are increased to compensate for channel losses. However, releases are not increased to compensate for flow lag/attenuation. At this time, *SIMD* has no capabilities for forecasting the number of days in advance that a reservoir release must be made to meet a downstream water supply diversion requirement.

CHAPTER 4 ROUTING PARAMETER CALIBRATION

Methods incorporated in *SIMD* for routing changes in daily flows are described in the preceding Chapter 3. Chapter 4 outlines capabilities provided by the *Daily Flows (DAY)* and *Daily Hydrographs (DAYH)* programs for estimating values for the parameters employed in the routing computations.

Either the *SIMD* lag and attenuation method or the *SIMD* adaptation of the Muskingum method may be adopted for routing stream flow adjustments. The lag and attenuation method was developed specifically for *SIMD* and is the standard recommended option for most *SIMD* applications. The control points for which routing is to be applied must be selected and values must be estimated for the routing parameters. Different parameter values may be entered at a control point for flow changes associated with flood control *FR* record reservoir operations and flow changes for *WR* record rights. The routing parameters (*RPARAMS(cp,I)*, I=1,4) entered on the *RT* record in a *SIMD* input DIF file for an upstream control point consist of either:

- LAG and ATT for normal operations and LAGF and ATTF for flood operations for use in the *SIMD* lag and attenuation routing method.
- MK and MX for normal operations and MKF and MXF for flood operations for use in the *SIMD* adaptation of the Muskingum routing method.

Programs *Daily Flows (DAY)* and *Daily Hydrographs (DAYH)* described in Appendices A and B, respectively, provide sets of optional routines designed to facilitate compilation of daily flow data and estimation of values for routing parameters. Programs *DAYH* (Appendix B) and *DAY* (Appendix A) were developed during 2005-2010 and 2016-2018, respectively. The calibration routine in the old *DAYH* (original *DAY*) employs a genetic optimization algorithm to determine parameter values that best replicate entire hydrographs. The calibration routine in the new *DAY* is based on statistical analyses of upstream and downstream changes in stream flow. The more recently developed *DAY* methodology based on statistical analyses of flow changes is the recommended option for calibrating *SIMD* routing parameters.

The original optimization-based parameter calibration methodology using entire upstream and downstream hydrographs is applicable to both the Muskingum and lag/attenuation methods. The newer calibration strategy based on statistical analysis of flow changes is applicable only to the lag/attenuation routing method.

Lag and Attenuation Analyses Capabilities of Program *Daily Flows*

Program *Daily Flows (DAY)* described in Appendix A is distributed as the executable file *DAY.exe* and for brevity is called program *DAY*. Program *DAY* is a set of routines designed to facilitate, in conjunction with *HEC-DSSVue*, compilation of various forms of flow data and to estimate values for routing parameters. The program provides a set of routines for compiling daily flow data, computing lag and attenuation metrics used to estimate values for routing parameters, disaggregating monthly flows to daily, and performing statistical frequency and regression analyses. The following discussion focuses on the *DAY* lag and attenuation analysis methodology designed to support estimation of values for routing parameters.

Program *Daily Flows (DAY)* does not automatically determine values for the routing parameters LAG, ATT, LAGF, and ATTF, but rather provides quantitative information to be considered within a framework of professional judgement to support estimation of the values of the parameters. The overall calibration strategy is outlined as follows.

1. Routing reaches are specified by selecting WRAP control points and U.S. Geological Survey (USGS) gaging stations that define the upstream and downstream ends of the routing reaches.
2. *HEC-DSSVue* is employed to download observed flows from the USGS National Water Information System (NWIS) to a DSS file to be read by the WRAP program *DAY*.
3. For a specified routing reach, criteria are specified in the program *DAY* input DIN file to define flow changes at the upstream and downstream gaging stations. Flow changes are specified as either flow increases or decreases and are constrained by various specified limits.
4. Lag and attenuation are computed by *DAY* for each of the flow changes.
5. Frequency metrics are computed by *DAY* for the lags and the attenuations of the flow changes. The frequency metrics include the mean, standard deviation, and quantities that are equaled or exceeded by specified percentages of the flow changes.
6. Professional judgment is applied in assigning values to the routing parameters LAG and ATT or LAGF and ATTF based on the results of the frequency analysis of numerous observed lags and attenuations. For example, the lag routing parameter LAG could be assigned as the median (50% exceedance frequency) of the observed lags compiled with *DAY*.
7. Values for LAG, ATT, LAGF, and ATTF at reaches between gaging stations with ample observed daily flow data can be used to estimate values for other stream reaches with inadequate or no observed daily flow data based on reach lengths and/or other reach characteristics.

The terms "lag" and "attenuation" are applied to both the individual lags and attenuations for each of numerous flow change events in a long record of observed flows and the routing parameters LAG, ATT, LAGF, and ATTF recorded on *RT* records in a *SIMD* input DIF file. The purpose of the lag and attenuation routine in program *DAY* is to provide a basis for assigning values for the lag and attenuation routing parameters LAG, ATT, LAGF, and ATTF employed in the *SIMD* simulation model.

Lag and Attenuation Analysis Computations

Daily flows are typically expressed as a mean flow during the day in units of cubic feet per second (cfs) or as a volume during the day in acre-feet per day (ac-ft/day). A mean flow of 1.0 cfs for 1.0 day has a volume of 1.0 second-foot-day (cfs×day) or 1.9835 acre-feet. Flow changes are likewise expressed as changes in mean daily flow in cfs or changes in daily volume in ac-ft/day. However, any other units including metric units can be employed in applying *DAY*.

The *DAY* lag and attenuation analysis is performed for a river reach based on daily flow changes at the upstream and downstream ends of the reach. Lag and attenuation, as defined on the next page, are computed for flow change events which may have durations of one day or multiple days. Input parameters on the job control *JC* record controlling the computations are

defined in Appendix A. Fundamental concepts of the program *DAY* computations are reflected in the following definitions.

Flow Change (FC): The flow change at a control point for each day is computed as the daily flow that day less the daily flow in the preceding day. The analysis can be performed for either flow decreases or flow increases. With *JC* record JOB option 3, flow changes are defined as decreases in flow. Conversely, with JOB option 4, only flow increases are employed in the computations. If flow changes are defined in terms of decreasing flow, the absolute value of the flow change is employed in the computations, meaning flow changes are always defined as positive numbers.

Flow Change Event: For JOB option 3, a flow change (FC) event consists of a continuous daily decrease in flow over one or more days. The event is ended by one or more days of increasing flow or no change. For change JOB option 4, a flow change event consists of an increase in flow over one or multiple days. The event is ended by one or more days of decreasing flow or zero flow change.

Duration of Flow Change Event: The duration is the integer number of days of the FC event. For example, a flow decrease event is by definition preceded and followed by one or more days of either increasing flow or zero change in flow. The duration is the number of days of decreasing flow that comprise the decreasing-flow FC event.

Instantaneous Peak of Flow Change Event (Q_P): The instantaneous peak is estimated as a function of the flow change during the peak day and adjacent days based on a linear interpolation scheme. However, Q_P is used in the computations solely for computing the timing. Although the peak of the flow rate change Q_P is not used, the time in days of Q_P is used in the computations. Q_P is included for information in the output table created by if FC DAY option 4 is activated in *JC* record field 11.

Peak Flow Time (T_P): If a flow change (FC) event has a duration of only one day, the peak is assumed to occur in the middle of the one day. If an FC event has a duration of two or more days, the time (T_P) of the peak in days along with Q_P are estimated as a function of the flow change during the day with greatest change and adjacent days based on a linear interpolation scheme.

Lag: The lag in days is the difference in T_P for a change event at the upstream end of the reach and the T_P for the next later occurring change event at the downstream end of the reach. The peak of the selected event at the downstream control point has a T_P that exceeds the T_P for the event at the upstream end of the reach. The lag is the difference between the downstream and upstream T_P.

Attenuation (Att): The attenuation corresponding to a lag is the ratio of the durations of the upstream and downstream events. $Att = \text{upstream duration} / \text{downstream duration}$

The *DAY* procedure controlled by *JC* record parameters results in series of flow change FC events occurring at the upstream and downstream ends of a stream reach. The lag parameter *LP* record provides optional criteria for use in selecting which of the FC events are included in

the compilation of values for lag and attenuation. The frequency analysis routine activated by *FREQ* on the *JC* record can be applied to compute statistics for these data series of lags and attenuations. The regression and correlation analysis routine activated by *REGCOR* on the *JC* record can be employed to relate lag and attenuation to flow.

The methodology for estimating the instant in time (T_P) at which the peak (Q_P) of a flow change (FC) event occurs is based on the flow changes occurring during the day with the maximum change (called the peak day), the day preceding the peak day, and the day following the peak day. If the duration of a FC event is one day, the peak is assumed to occur at the center of that day. The following strategy is applied for FC events with durations of two or more days. The objective of this computational procedure is to estimate the time T_P at which the peak Q_P of the FC occurs. Although not actually used in the final analysis, the accompanying peak flow rate Q_P is also estimated in the process of computing the T_P and is included in the *FCDAY* option 4 output table.

Q_2 denotes the mean rate of change in flow (FC) during the day with the greatest change. Q_1 and Q_3 denote the FC in the day immediately before Q_2 and the day after Q_2 . The following instantaneous rates of flow change are assumed, which are based on averaging rates of flow change for adjoining days.

$$\begin{array}{ll} \text{rate at beginning of peak day} & Q_A = 0.5(Q_1+Q_2) \\ \text{rate at end of peak day} & Q_B = 0.5(Q_2+Q_3) \end{array}$$

The FC is assumed to increase linearly from the beginning of the peak day to Q_P at T_P and then decrease linearly to the end of the peak day. The total FC volume of the peak day is maintained. Based on these assumptions, geometry yields the following equation.

$$Q_P = 1.5Q_2 - 0.25Q_1 - 0.25Q_3$$

If Q_1 , Q_2 , and Q_3 are equal, $Q_P = Q_1 = Q_2 = Q_3$. Otherwise, Q_P is greater than the flow in the peak day which is greater than the flow in the adjoining days.

The fraction of a day X denotes the time between the beginning of the peak day and T_P . The time between T_P and the end of the peak day is $(1.0 - X)$. Equal linear slopes are assumed between the beginning of the peak day and T_P and between T_P and the end of the peak day.

$$\begin{aligned} \text{Slope} &= (Q_P - Q_A)/X = (Q_P - Q_B)/(1.0 - X) \\ \text{Slope} &= (Q_P - 0.5(Q_1+Q_2))/X = (Q_P - 0.5(Q_2+Q_3))/(1.0 - X) \end{aligned}$$

This expression is solved for X .

$$X = (Q_P - Q_A)/(2.0 \times Q_P - Q_A - Q_B)$$

The fraction of a day X is added to the time of the beginning of the peak day in days since time zero to obtain the time of the peak T_P .

$$T_P = \text{time of beginning of peak day} + X$$

Example Illustrating Lag and Attenuation Computations

The daily mean flows and changes thereof at the upstream (US) and downstream (DS) ends of a river reach during May 6-19, 2015 tabulated in Table 4.1 are used to illustrate the lag and attenuation computations. The peak flow change days (days 130 and 132) for this pair of upstream and downstream flow change FC events are identified in Table 4.1 with boxes.

Table 4.1
Flow Changes for the Lag and Attenuation Example

Day	Year	Month	Day of Month	Flow US (cfs)	Flow DS (cfs)	Change US (cfs)	Change DS (cfs)
127	2015	5	6	5,215	9,681	0	0
128	2015	5	7	10,103	9,484	0	197
129	2015	5	8	8,370	11,002	1,733	0
130	2015	5	9	5,046	10,642	3,324	360
131	2015	5	10	2,875	8,003	2,171	2,639
132	2015	5	11	2,332	4,916	543	3,087
133	2015	5	12	2,257	3,954	75	962
134	2015	5	13	2,066	3,392	191	562
135	2015	5	14	1,671	2,649	395	743
136	2015	5	15	1,299	1,911	372	738
137	2015	5	16	1,208	1,478	91	433
138	2015	5	17	1,358	1,314	0	164
139	2015	5	18	1,441	1,518	0	0
140	2015	5	19	1,528	1,701	0	0

Upstream (US) Flow Change Metrics

$$Q_1 = 1,733 \text{ cfs} \quad Q_2 = 3,324 \text{ cfs} \quad Q_3 = 2,171 \text{ cfs}$$

$$Q_A = 0.5(Q_1 + Q_2) = 0.5(1,733 + 3,324) = 2,528.5 \text{ cfs}$$

$$Q_B = 0.5(Q_2 + Q_3) = 0.5(3,324 + 2,171) = 2,747.5 \text{ cfs}$$

$$Q_P = 1.5Q_2 - 0.25Q_1 - 0.25Q_3 = 1.5(3,324) - 0.25(1,733) - 0.25(2,171) = 4,010 \text{ cfs}$$

$$X = (Q_P - Q_A) / (2.0Q_P - Q_A - Q_B) = (4,010 - 2,528.5) / (2.0 \times 4,010 - 2,528.5 - 2,745.5) = 0.54 \text{ day}$$

$$T_P = \text{time of beginning of peak day} + X = 129.00 \text{ days} + 0.54 \text{ day} = 129.54 \text{ days}$$

$$\text{Duration} = 9 \text{ days}$$

Downstream (DS) Flow Change Metrics

$$Q_1 = 2,639 \text{ cfs} \quad Q_2 = 3,087 \text{ cfs} \quad Q_3 = 962 \text{ cfs}$$

$$Q_A = 0.5(Q_1 + Q_2) = 0.5(2,639 + 3,087) = 2,863.0 \text{ cfs}$$

$$Q_B = 0.5(Q_2 + Q_3) = 0.5(3,087 + 962) = 2,024.5 \text{ cfs}$$

$$Q_P = 1.5Q_2 - 0.25Q_1 - 0.25Q_3 = 1.5(3,087) - 0.25(2,639) - 0.25(962) = 3,730.25 \text{ cfs}$$

$$X = (Q_P - Q_A) / (2.0Q_P - Q_A - Q_B) = (3,730.25 - 2,863.0) / (2.0 \times 3,730.25 - 2,863.0 - 2,024.5) = 0.34$$

$$T_P = \text{time of beginning of peak day} + X = 131.00 \text{ days} + 0.34 \text{ day} = 131.34 \text{ days}$$

$$\text{Duration} = 9 \text{ days}$$

Lag and Attenuation

$$\text{Lag} = 131.34 \text{ days} - 129.54 \text{ days} = 1.80 \text{ days}$$

$$\text{Attenuation} = \left(\frac{9 \text{ days}}{9 \text{ days}} \right) (1 \text{ day}) = 1.00 \text{ day}$$

Criteria for Selecting Flow Change Events

Observed daily flows at two gaging stations over a long period-of-record will contain numerous flow change FC events. The preceding example illustrates the computation of the lag and attenuation for just one FC event. The flows for 14 days (days 127 through 140) included in the table on the preceding page are excerpted from a long flow series extending over several thousand days. The single pair of upstream and downstream FC events contained within the 14 days included in the table are among hundreds of FC events found in the entire long flow sequence. Criteria for defining flow change events are specified on the lag parameter *LP* record.

Flow changes used in computing lag and attenuation must be either flow decreases (JOB option 3) or increases (JOB option 4). The example employs *JC* record JOB option 3. The optional lag parameter *LP* record provides a set of additional criteria for selecting which of the FC events are adopted for compiling a series of lag and attenuation quantities. The preceding example adopts defaults for all the parameters on the *LP* record, and thus the *LP* record would not be employed. However, the following *LP* record criteria can be applied in limiting the set of lags and attenuations included in the final compilation. The objective is to limit consideration to FC events that provide the most accurate estimates of the lag characterizing downstream propagation of flow changes.

- Parameter LP1 sets a minimum time between the T_P at the upstream and downstream ends of the reach. By default, the next downstream event at the same or future instant in time is selected. Otherwise with a non-zero LP1, the next downstream flow change event with a T_P at least LP1 days later than the upstream T_P is paired with the upstream event in computing lag.
- Parameter LP2 allows consideration of flow changes at the downstream site that are occurring simultaneously during the peak day of the FC event at the upstream site. Downstream flow changes may result from incremental lateral inflows or losses as well as from changes at the upstream site. The objective is to exclude FC events for which downstream FCs are not caused primarily by the upstream FCs. With a non-zero positive LP2 entered on the *LP* record, an event is included only if the downstream FC does not exceed the upstream peak day FC in that same day by more than $FC \times LP2$. For example, with LP2 set at 0.25, a decreasing flow event will not be included in the compilation if the downstream flow decrease during the upstream peak flow day exceeds 25% of the upstream flow decrease during that same day.

- LP3, LP4, LP5, and LP6 entered on the *LP* record place upper and lower limits on the upstream and downstream daily flow changes adopted for the analysis. Lags and attenuations computed from flow changes falling outside the specified limits are removed from the final compilation.
- LP7, LP8, LP9, and LP10 specify upper and lower limits on the daily flows adopted for the computations at the upstream and downstream ends of the reach. Lags and attenuations computed from flow falling outside the limits are removed from the final compilation.

Other Features of Lag and Attenuation Analyses

The alternative strategies for employing more than two control points to specify flows at the upstream and downstream ends of a river reach described in this paragraph and the next is the only difference between JOB options 3 and 4 and JOB options 5 and 6. With only two control points on the *CP* record, there is no difference. With JOB options 3 and 4, only one reach is considered. With JOB options 5 and 6, if the number of control points on *CP* records is greater than two, the last control point represents the downstream end of the reach. The daily flows at all of the others are summed to obtain the total daily flows at the upstream end of the reach.

With JOB options 5 and 6, control points on *CP* records may define the upstream and downstream ends of any number of reaches. With JOB options 5 and 6 combined with multiple control points on *CP* records (NCP greater than 2), the first lag/attenuation analysis uses the first control point listed on the *CP* record as the upstream end of the reach, and the second control point is the downstream end. The second lag/attenuation analysis employs the second control point listed on the *CP* record as the upstream end of the reach, and the third control point is the downstream end. For the third lag/attenuation analysis, the third and fourth control points are the upstream and downstream ends of the reach. Next, the fourth and fifth control points are paired and so forth.

Computed lags in units of days are zero or positive numbers. Computed attenuations are positive numbers that are always greater than zero. Each computed lag has a corresponding computed attenuation. The lags and attenuations are assigned to the day of the flow change event that has the peak flow change at the upstream end of the river reach. The days with an assigned lag and attenuation are a subset of all of the days of the period-of-analysis. The frequency analysis and regression and correlation analysis routines are applied to all computed lags and attenuations, but exclude all days not assigned lag/attenuation. Lag may include zero as well as positive numbers. The attenuations are all positive numbers, with no zeros.

At the beginning of the computations, a lag value of -9.0 is assigned to all days of the period-of-analysis defined on the *JC* record. A value of 0.0 is assigned for attenuation for each of the total number of days in the period-of-analysis. The -9.0s and 0.0s are replaced as computed lags and attenuations are assigned to the appropriate upstream peak flow days. The final results of the lag and attenuation computation routine is a compilation of lag and attenuation values. The *LP* record criteria control removal of lag and attenuation values from the compilation. A -99.0 and 0.0 are assigned to the lag and attenuation for the days in which the computed lag and attenuation are removed. Several of the output options specify tabulations for all days of the

period-of-analysis. Lags are shown as -9.0 and -99.0 for the days without adopted computed lags. The parameter L99 on the *LP* record provides the option of converts the -9.0s and -99.0s to 0.0s.

Output options for the quantities computed in the lag and attenuation analysis are selected using *JC* record switch parameters FCDSS and FCDAAY. The most detailed tabulation of computation results is created by FCDAAY option 4. Frequency analyses are activated by *JC* record parameter FREQ. Regression and correlation analyses are activated by *JC* record REGCOR. Frequency analyses can be applied to the series of lag and attenuation values to support selection of the routing parameters employed in a *SIMD* simulation. Regression and correlation analyses relate lag and attenuation to stream flow.

Parameter Calibration Capabilities of Program *Daily Hydrographs*

Calibration routines in *DAYH* are based on computing values for routing parameters for reaches between control points based on the known naturalized flows or other given flows at the control points. The calibrated parameter values are then input to *SIMD* on DIF file *RT* records for use in propagating changes in stream flows occurring during the water rights simulation.

The alternative routing parameter calibration methodologies employed in *DAYH* described here and *DAY* described in the preceding sections are compared as follows.

- *DAYH* uses a genetic algorithm or iteration to determine parameter values that replicate entire hydrographs. Calibration with *DAY* is based on statistical analyses of flow changes.
- *DAYH* is applicable to both the Muskingum and lag/attenuation methods. *DAY* is applicable only to the lag/attenuation method. *DAY* is used to calibrate LAG, ATT, LAGF, and ATTF. *DAYH* calibrates MK, MX, MKF, and MXF as well as LAG, ATT, LAGF, and ATTF.
- Both methodologies are based on analyzing daily streamflow hydrographs. Both could be applied to either observed gaged flows or naturalized flows. Observed gaged flows will typically be applied with the *DAY* methodology to capture actual flow changes caused by human actions. The *DAYH* methodology is applied with either naturalized or observed flows.
- Programs *DAYH* and *DAY* were developed during 2005-2010 and 2016-2017, respectively. Program *DAYH* was originally called *DAY*.
- Both programs use DIN, DMS, DAY, FLO, and DCF input and output files. Program *DAY* also uses DSS input and output files.
- Programs *DAYH* and *DAY* are described in Appendices B and A, respectively.

Program *Daily Hydrographs (DAYH)* Calibration Features

A calibration job in the WRAP program *DAYH* consists of computing routing parameters for a single river reach or for multiple reaches ending at the same downstream control point. Two or more control points define the upstream and downstream end of a reach. *DAYH* has an optimization option that simultaneously calibrates two or more reaches that share a common downstream confluence. Multiple jobs may be included in a *DAYH* dataset to determine routing parameters for any number of routing reaches. Appropriate control points are defined for each individual calibration job.

Program *DAYH* reads naturalized monthly flows from a FLO file and sub-monthly (daily) flows or flow patterns from a DCF file. All other *DAYH* input is read from a DIN file. File extensions are listed in Table 1.2. Programs *SIMD* and *DAYH* may read the same FLO and DCF files. *DAYH* reads flow data for only those control points that are pertinent to that execution.

The entire hydrologic period-of-analysis or any sub-portion thereof may be used to determine parameters for any user-selected control points. The user may define sequences of flows used in the *DAYH* calibration computations by specifying the beginning and ending dates. For example, flood events may be selected for calibrating parameters for flood flows. *DAYH* also provides an option for specifying the range of flow to be used in the calibration. Flow range criteria are specified in terms of flow magnitude at the upstream control point.

Gains or Losses of Flow in a River Reach

Parameter calibration is complicated by flow gains and losses between the upstream and downstream ends of the routing reach. Channel losses include seepage, evapotranspiration, and unaccounted diversions. Precipitation runoff from local incremental watersheds as well as subsurface flows may enter the river along the routing reach. The same control point may be the downstream limit of two or more tributary streams. Multiple tributaries may enter the river reach at various locations between its upstream and downstream ends. Calibration is more accurate for river reaches with minimal change in volume between the upstream and downstream ends.

The *DAYH* parameter calibration routines include an option for adjusting the downstream outflow hydrograph to contain the same total volume during the overall calibration period-of-analysis as the upstream inflow hydrograph. The daily outflows (O_T) at the downstream control point are adjusted based on mean volumes of inflow (I_{mean}) and outflow (O_{mean}) as follows.

$$\text{Adjusted } O_T = O_T \left(\frac{I_{\text{mean}}}{O_{\text{mean}}} \right) \quad (4.1)$$

With this volume adjustment approach, the hydrograph at the downstream control point is viewed as being composed of two components: (1) flows from the upstream control point(s) and (2) flows entering the reach downstream of the upstream control point(s). The two component hydrographs are assumed to have the same pattern as the combined flows at the downstream control point and are separated in proportion to total volume summed over the entire calibration period. The calibration may be performed either with or without the volume adjustment option.

Alternative Methods for Calibrating Routing Parameters

The calibration addressed here consists of finding values for routing parameters that, given a known upstream stream flow hydrograph, result in a computed downstream hydrograph that best reproduces a given known downstream hydrograph. The given upstream and downstream hydrographs provided as input to *DAYH* are typically the naturalized flows from the *SIMD* dataset. The time series of daily flows used in the *DAYH* calibration computations may be input to *DAYH* directly as daily flows or computed by *DAYH* by disaggregating inputted monthly flows. *DAYH* disaggregates monthly flows to daily flows in the same manner as *SIMD*.

Program *DAYH* provides the following three alternative approaches for performing calibration computations. Calibration features described in the preceding paragraphs are essentially the same with either of the three alternative computational options.

- The *iterative simulation* option consists of *DAYH* performing the routing computations with user-specified values for the parameters and developing a table of indices that compare differences between the computed versus given downstream hydrographs.
- The *optimization option* uses a genetic search algorithm that determines values for the parameters based on repeating the routing numerous times in an automated search for the parameter values that minimize specified objective functions that are based on deviations between computed and known downstream flows.
- The *direct Muskingum option* consist of determination of K from linear regression for assumed values of X based on the Equation 3.10 definition of K and X.

The first two options are applicable to either the lag and attenuation method or the Muskingum method. The third method is applicable only to the Muskingum method. The optimization option expands the iterative simulation option by automating the repetitive search.

The iterative simulation and optimization options may be adopted either with or without adjusting the known flows for incremental net gains less losses between control points using Equation 3.15. The Eq. 3.15 adjustments remove incremental inflows less losses from the outflows, such that the total volume of inflows and outflows are the same over the total calibration period. Inherent in the Eq. 3.15 adjustment approach is the premise that the daily incremental net inflows have the same daily flow pattern as the total daily outflows at the downstream control point. An alternative option discussed later is designed to remove this assumption, allowing the daily flow pattern of the incremental net inflows to be completely different than the daily flow patterns at either the downstream or upstream control points.

Iterative Simulation Option

The iterative simulation optimization approach consists of determining optimal values for the routing parameters by adjusting the parameter values in iterative executions of *DAYH* while attempting to find those parameter values for which downstream flows computed by *DAYH* match the downstream flows provided as input to *DAYH* as closely as possible. The flow comparison feature of *DAYH* consists of developing a table that is recorded in the DMS file with the following information.

identifiers of upstream and downstream control points defining reach
period of time covered by the calibration computations
range of flows covered by the calibration computations
type of routing method at the upstream control point(s)
user defined values of the routing parameters at the upstream control point(s)
values for objective functions F_1 , F_2 , F_3 , F_4 , and F_5 defined by Eqs. 4.4–4.9
comparative flow statistics:
total volume

- percent of outflow hydrograph
- mean of flow
- standard deviation of flow
- flow percentiles

comparative difference statistics:

- mean of differences (computed flow – given flow)
- mean of absolute value of differences (computed – given)
- mean of positive differences (computed flow – given flow)
- mean of negative differences (computed flow – given flow)
- mean of differences (computed flow – given flow) squared
- largest positive difference (computed flow – given flow)
- largest negative difference (computed flow – given flow)

The model-user executes *DAYH* multiple times with different values for the parameters. The parameter values are revised based on judgment and the comparison statistics provided by *DAYH*. The optimum values for the parameters are those values for which the comparison statistics and objective functions listed above are zero or as close to zero as possible.

Program *DAYH* includes an option for computing values of the comparison statistics and objective functions for a user specified range of flow. The flow range criteria are specified in terms of flow at the upstream control point. The lag and attenuation or Muskingum routing computations are applied identically the same regardless of the flow range of interest specified by the user. However, only the days with upstream flows falling in the specified range are used in computing values of the comparison statistics and objective functions.

The optimization option discussed next represents the same general procedure as the iteration simulation option with the major exception that the repeats of the routing computations with difference parameter values are automated within *DAYH*. With the iterative simulation option, the model-user manually inputs revised parameter values for each repetitive execution of *DAYH*. The objective functions F_1 , F_2 , F_3 , F_4 , and F_5 described in the next section are computed with either the iterative simulation option or optimization option. The weighting factor W defined later by Eqs. 4.8 and 4.9 is provided as input to activate the computational options associated with F_4 and F_5 with either the iterative simulation or optimization options.

Automated Optimization Option

The genetic optimization algorithm based calibration strategy automates the repetition of the routing computations with different values for LAG and ATT, or LAGF and ATTF, or MK and MX, or MKF and MXF in an iterative search for the optimum values that minimize a defined objective function. For given values of the two parameters, the inflows (I_T) are routed to compute the outflows (O_T). An objective function is evaluated based on comparing known and computed outflows. The computations are repeated until the solution converges on the optimum combination of routing parameters.

Various types of search algorithms are available for this type of optimization problem. The USACE Hydrologic Engineering Center (HEC) Hydrologic Modeling System (HMS) has

two alternative gradient search algorithms used for calibrating the Muskingum K and X routing parameters as well as for calibrating parameters for various watershed precipitation-runoff models. *WRAP-DAYH* uses an optimization strategy based on a genetic search algorithm. Genetic algorithms are evolutionary search techniques based on the mechanics of natural selection. A genetic algorithm is a type of directed stochastic optimization strategy. Genetic search algorithms may have an advantage over gradient search or deterministic optimization methods in that they may be less likely to converge on local rather than global optima. The genetic search algorithm incorporated in *DAYH* for parameter calibration is described by Hoffpaur [11].

The optimization option allows simultaneous calibration for multiple reaches defined by a common downstream control point and a different upstream control point for each river reach entering the confluence. The routing algorithm is applied to compute the outflows given the known inflow sequence for each of the river reaches. The outflows are summed to obtain the total outflows ($O_{\text{computed}} = \sum O_{\text{reach}}$) used in the objective function evaluation.

The model-user may place upper and lower limits on the values of the parameters to be considered in the calibration. The user may also fix one or both parameter values in certain reaches while optimizing the other parameter for the same reach or both parameters for other reaches. Simulations may be performed with all parameters fixed in order to compare values of the alternative objective functions.

The optimum values for the two routing parameters for the one or more reaches are defined in terms of minimizing an objective function expressing criteria for measuring the closeness in reproducing known outflows. The objective function is computed from the results of the routing. Routing computations are performed with many different sets of parameter values in a search for those values that yield the optimum value of the objective function. *DAYH* provides the following optional objective function formulations. The alternative objective functions described below (F_1 , F_2 , F_3 , F_4 , and F_5) all have dimensions of flow volume per time step. All are designed to be minimized in the optimization algorithm.

Objective function option 1 is the least squares criterion based on minimizing the sum of the squares of the deviations between the known flows (O_{known}) at the downstream control point and the computed flows (O_{computed}). The objective (criterion) function (F) is expressed as Eq. 4.2, where N is the number of time steps (days) in the routing computations.

$$F_1 = \sqrt{\frac{\sum^N (O_{\text{known}} - O_{\text{computed}})^2}{N}} \quad (4.2)$$

The known flows (O_{known}) may reflect adjustments using Eq. 4.1 to account for net lateral inflows in the total volume balance. By squaring the differences between the known and routed flows each period, larger deviations are magnified more in the weighting of daily deviations resulting in a more even distribution of deviation magnitudes over time. However, since larger differences tend to be associated with larger flows, larger flows will tend to have a greater influence on the optimization computations than smaller flows.

The second option is the absolute deviation criterion with the objective function defined identically to the first option except the deviations are not squared. Equation 4.3 is minimized. The absolute value (abs) converts negative differences to positive numbers in the summation.

$$F_2 = \frac{\sum_N \text{abs} (O_{\text{known}} - O_{\text{computed}})}{N} \quad (4.3)$$

Equations 4.2 and 4.3 may be adopted either with or without adjusting the known flows (O_{known}) using Eq. 4.1. The Eq. 4.1 adjustments remove incremental net lateral inflows from the outflows, such that the total volume of inflows and outflows are the same over the total calibration period. Inherent in the Eq. 4.1 adjustment approach is the premise that the daily lateral inflows have the same daily flow pattern as the total daily outflows at the downstream control point. The third objective function formulation is designed to remove this assumption, allowing the daily flow pattern of the lateral inflows to be completely different than the daily flow patterns at either the downstream or upstream control points.

Objective function option 3 is based on computing the daily incremental net inflows less losses between the control points (also called lateral inflows) as the difference between the known outflows (O_{known}) and routed outflows (O_{computed}). Equation 4.1 is not applied.

The total flow volume over the total calibration period at the downstream control point is the sum of the flows at the one or more upstream control points plus the lateral flows entering the river reach between the upstream and downstream control points. The known total lateral flow volume (Q_{lateral}) over the entire calibration period is the total outflow less total inflow (Eq. 4.4).

$$\text{Total Lateral Flow Volume} = Q_{\text{lateral}} = \sum_N O_{\text{known}} - \sum_N I_{\text{known}} \quad (4.4)$$

The portion of the daily flow volume at the downstream control point in a given day attributable to net lateral inflow is the known daily outflow volume (O_{known}) less the routed daily outflow volume (O_{computed}) for that day.

$$\text{Daily Lateral Flow Volume} = O_{\text{known}} - O_{\text{computed}} \quad (4.5)$$

$$\text{Total Lateral Flow Volume} = \sum_N \text{Daily Lateral Flow Volumes} \quad (4.6)$$

The objective of the third criterion function option is to find values for the routing parameters that minimize the difference between the two alternative summations (Eqs. 4.4 and 4.6) representing total lateral flow volume over the entire calibration period covering N sub-monthly (daily) time steps. The desired value is zero for the objective function (F_3) defined by Eq. 4.7. The search algorithm is driven by minimizing Eq. 4.7.

$$F_3 = \frac{\text{Abs} \left(Q_{\text{lateral}} - \sum_N (O_{\text{known}} - O_{\text{computed}}) \right)}{N} \quad (4.7)$$

The relative advantage between the objective function F_3 of Eq. 4.7 applied without the Eq. 4.1 adjustment versus either F_1 or F_2 (Eqs. 4.2 or 4.3) applied either with or without the Eq. 3.15 adjustment depends on the characteristics and relative magnitude of the lateral flows entering or leaving the reach between the upstream control point(s) and the downstream control point. F_3 allows lateral inflows to be more accurately modeled in the calibration process without fixing the flow pattern as being the same as total outflows. Use of Eq. 4.1 with objective function F_1 or F_2 reflects a more approximate representation of lateral flows. However, the F_1 or F_2 options minimize the deviations between the daily computed and observed outflows. With only minimal lateral flows, F_1 and F_2 are clearly better objective functions than F_3 .

Objective function alternatives F_4 and F_5 address tradeoffs between the concepts outlined above by combining F_3 with either F_1 or F_2 .

$$F_4 = (1.0 - W) F_1 + W F_3 \quad (4.8)$$

$$F_5 = (1.0 - W) F_2 + W F_3 \quad (4.9)$$

The weighting ($0.0 \leq W \leq 1.0$) factor W sets the relative influence of F_3 . The value for W is rather arbitrary with a default W of 0.80 designed to assure that F_3 is forced to zero or at least very close to zero. Setting W equal to zero in Equations 4.8 or 4.9 has the same effect as adopting Equations 4.2 or 4.3 (F_1 or F_2).

The optimization algorithm searches for routing parameter values that minimize the objective function. Driving the F_3 component of F_4 or F_5 to zero maintains the volume balance for the overall calibration period (outflow = inflow at upstream control point(s) + lateral flow) while still allowing flexibility in the pattern of lateral flows. Minimizing the F_1 or F_2 component of F_4 or F_5 results in the routed outflows computed with Eq. 3.11 closely reproducing the general pattern of the known outflows. If the lateral flows are negligible, F_1 or F_2 should be used rather than F_4 or F_5 . The Eq. 4.1 option for adjusting outflows to maintain the volume balance normally should not be used in combination with F_3 , F_4 , or F_5 .

Reaches sharing a common downstream control point (confluence) are calibrated independently of each other except for volume balance adjustments of Equation 4.1. The optimization option allows simultaneous calibration for two or more reaches defined by a common downstream control point and a different upstream control point for each river reach entering the confluence. The optimization allows use of either the Equation 4.1 or F_3 objective function options to account for lateral inflows in balancing the total inflow and outflow volumes.

Reducing the Spread of Routed Flows

When the optimization option is selected for the calibration of lag and attenuation, the search space for lag and attenuation can include any valid values of the two parameters as defined by equations 4.10, 4.11, and 4.12.

$$Lag \geq 0.0 \quad (4.10)$$

$$Attenuation \geq 1.0 \quad (4.11)$$

$$Attenuation \leq 1.0 + Lag \quad (4.12)$$

Attenuation that is constrained only by equations 4.11 and 4.12 can allow routed flows to cover all time steps from the present to the last day of routing effects. For example, if lag is selected as 2.0 days, the valid range of attenuation that can be considered from the search space includes values from 1.0 to 3.0 days. With attenuation equal to 3.0 days, the downstream location will be simulated as receiving routed flows from the upstream end of the reach in the current day through the end of the second future day. In data sets where a weak optimum solution exists in the search space, lag and attenuation may be over predicted by a solution that encompasses a large range of flow routing conditions.

Most real-world stream reaches with more than a few weeks or months of stream flow data will experience a wide range of flow conditions. Flow events of various magnitudes will travel at different velocities through the stream reach. Variable contributions of lateral inflows from ungaged surface or subsurface sources will also add to a range of apparent velocity and attenuation as observed at the downstream end of the reach. Optimization of a single pair of lag and attenuation parameters over a large period of record is complicated by natural variability in velocity and attenuation of flow events. Where there is sufficient flow event variability, and in particular where large lateral inflows are present between the upstream and downstream ends of the reach, the search space for attenuation may require an additional constraint to avoid solutions that allow routed flows to spread out over a wide range of time steps.

Field 2 of the RTYPES record, parameter LF , is read when the user has selected at least one upstream gage for the lag and attenuation method for optimization. The value of field 2 is applied to all upstream gages during the optimization to directly constrain the search space of attenuation. The value of field 2 is shown in equation 4.13 as a multiplier to the value of lag. Equation 4.13 replaces equation 4.12 in the optimization calibration for values of LF less than 1.0. The value of LF is provided as any real number less than or equal to 1.0 with a default value 0.25. By constraining the search space of attenuation based on the value of lag, the pair of routing parameters will tend towards solutions that reduce the number of time steps over which the routed flows are spread. Optimized values of lag will indirectly be affected by the choice of LF in response to the upper limit to values of attenuation.

$$Attenuation \leq 1.0 + (LF) Lag \quad (4.13)$$

Direct Calibration Option for Muskingum K and X

The iterative simulation and optimization options described in the preceding sections are applicable to either the lag and attenuation routing method or Muskingum method. The third option described below is applicable to only the Muskingum method. The optimization option allows simultaneous calibration for two or more reaches defined by a common downstream control point and a different upstream control point for each river reach entering the confluence. The direct option described below is applicable only for an individual river reach defined by a downstream control point and one upstream control point.

The direct calibration method consists of computation of K for assumed X based on the fundamental definition of the parameters K and X reflected in Equation 4.15.

$$\frac{S_T - S_{T-1}}{\Delta t} = I_T - O_T \quad (4.14)$$

$$S_T = K [X I_T + (1.0 - X) O_T] \quad (4.15)$$

The variables are defined as follows.

- Δt – day or other sub-monthly time interval
- K – parameter MK or MKF to be determined, same units as Δt
- X – dimensionless parameter MX or MXF to be determined, $0.0 \leq X \leq 0.5$
- S_{T-1} – storage volume at the end of day T-1
- S_T – storage volume at the end of day T
- I_{T-1} – inflow volume during day T-1
- I_T – inflow volume during day T
- O_{T-1} – outflow volume during day T-1
- O_T – outflow volume during day T

The subscripts T-1 and T refer to successive time steps such as days. Storage (S) and the weighted flow term (XI+(1.0-X)O) are computed stepping through time with the subscripts T and T-1 serving as moving indices. The parameter X represents a relative weighting of inflow (I) and outflow (O) in determining storage volume (S) in a river reach. K is the constant of proportionality or slope term in the linear function (Eq. 4.15) relating S to weighted I and O.

S denotes the volume of water stored in the river reach at an instant in time. However, storage changes rather than absolute magnitudes are of concern in the calibration procedure. The slope, not the intercept, of the S versus (XI+(1-X)O) relationship is of concern. S may be defined as the cumulative total storage volume above an arbitrary storage reference datum, typically taken as the unknown storage that existed at the beginning of the time series of inflows and outflows used in the calibration computations. Thus, S is the cumulative storage volume at an instant in time cumulated since a defined time zero.

The change in storage volume in a river reach occurring between two points in time equals the summation of inflow less outflow volumes during each incremental time interval spanning these two points in time. Change in storage (ΔS) during a time step of size Δt is computed as follows.

$$\Delta S = \sum (I \Delta t - O \Delta t) \quad (4.16)$$

The total volume of storage (S_T) at time T that has accumulated since the beginning of the computations at time zero is as follows.

$$S_T = \sum \Delta S \quad (4.17)$$

DAYH provides a parameter calibration routine based on computing K from a known time sequence of I_T and O_T with Eqs. 4.2, 4.3, 4.4, and 4.5 with an assumed value of X. K is defined by Eq. 4.15 which can be rewritten as Eq. 4.18.

$$K = \frac{S_T}{[X I_T + (1.0 - X) O_T]} \quad (4.18)$$

K is the slope of the relationship between S_T and $[X I_T + (1.0 - X) O_T]$.

Paired sequences of I_T and O_T are converted to paired sequences of $(XI_T+(1.0-X)(O_T))$ and S_T , with S_T computed with Eqs. 4.16 and 4.17. K is determined by applying linear least-squares regression to this paired series. K is the slope of the regression line. The computation of K is repeated for different values of X . The optimal values of X and K are those with the linear correlation coefficient (Eq. 2.17) being closest to 1.0.

The computations are based on sequences of reach inflows (I_T) and outflows (O_T) over some time span that could range from a single flood event to an entire WAM hydrologic period-of-analysis. Although K is assumed to be a constant, it represents flow travel time which may actually vary significantly with flow. *SIMD* allows two sets of X and K values to be input on *RT* records. The first set is used for routing flow changes for *WR* record water rights which are typically associated with normal and low flows. The second set of values for K and X values on the *RT* records are for flow changes caused by *FR* record flood control reservoir operations.

DAYH also has an option for computing K for a user specified range of flow. Flow range criteria are specified in terms of flow at the upstream control point. Equations 4.14, 4.15, 4.16, and 4.17 are applied to the hydrologic period-of-analysis daily naturalized flows at the two control points identically the same regardless of the flow range of interest specified by the user. However, in applying the regression analysis, only the pairs of S and $(XI+(1.0-X)O)$ associated with upstream flows falling in the specified range are used.

The conceptual basis of the *DAYH* computational methodology is the same as the graphical approach presented in hydrology textbooks [10]. Muskingum routing is based on the following premises, neither of which is strictly true but rather is approximately the case.

- There is a linear relationship between S and $(XI+(1.0-X)O)$.
- The parameters K and X are constants for a particular river reach.

If these two premises were perfectly valid, a plot of S and $(XI+(1.0-X)O)$ would be a straight line for a series of known inflows and outflows for the river reach. The optimal value of X results in the typical looped relationship being as close to a straight line or the correlation coefficient being close to 1.0 as possible. The parameter K is the slope of the line.

SIMD routes incremental flow changes, with the second premise being somewhat relaxed by allowing different K and X values for flood control operations versus normal flows. Other more conventional non-WRAP applications of Muskingum routing limit the method to modeling only flood events.

Program *DAYH* Routing Parameter Calibration Example

The following calibration example is based on an earlier version of the example presented in Chapter 7. The *DAYH* input and output files for the calibration example are as follows:

- DAYHexam.DCF – The DCF input file provides *DF* record daily flows.
- DAYHexam.DIN – The *DAYH* input DIN file is reproduced as Table 4.2.
- DAYHexam.DMS – The *DAYH* message DMS file is reproduced as Table 4.3.
- DAYHexam.DAY – The *DAYH* output file is reproduced as Table 4.4.

The first job in the calibration example optimizes over the entire 1960-1969 daily period-of-record to obtain values for the lag-attenuation parameters *LAG* and *ATT* to be entered on the *RT* records for the river reaches below the Belton and Granger control points. There are 3,653 time steps (days) in the optimization computations. Optimizing over the entire period-of-record is intended to find routing parameters to be used for "normal flow" non-flooding conditions. The optimization uses objective function 5 which is a combination of matching the absolute error (objective function 2) and reproducing the lateral inflow volume (objective function 3). The absolute error objective function may be preferable for finding the routing coefficients for the entire period-of-record. Using a squared error objective function may be more useful for determining flood flow routing parameters. The calibration results in a *LAG* and *ATT* of 1.55 and 1.00 days, respectively, for the Belton to Cameron reach. The Granger to Cameron reach is optimized simultaneously for *LAG* and *ATT* of 0.70 and 1.00 days, respectively.

The second job in the routing parameter calibration example isolates a flood peak in May 1965 for the river reach from the Bryan to Hemp gaging stations. Specifying a lower flow limit at the Bryan gage of 50,000 cfs reduces the available time steps in the month of May to 10. The direct solution option results in a best fit Muskingum *K* between 0.76 and 0.82 days based on the values of the correlation coefficient, *R*. The results of this example could be used for estimating the flood flow routing parameters *MKF* and *MXF* on the *RT* record. Estimating Muskingum routing parameters for different flood flow events may produce different sets of values for the routing parameters. Because the parameters *MKF* and *MXF* are applied to flood control operations over the entire period of record, multiple flood flow events are typically considered in order to get a set of average flood flow routing parameters.

Table 4.2
DAYH Input DIN File for Example

```

**
** File DAYHexam.DIN - WRAP-DAYH Input File for Example
**
** -----
** Routing parameter calibration over the period of record.
**
JOBRTG      1      0      5      0.80      3  Belton   Grang   Camer
RFLOWS      1960      1      1969      12      1
RTYPES      0.25      LA
RLOWER      0      1.0      0.0
RUPPER      0      3.0      2.0
CHECKS      1      1
**
** -----
** Direct solution for the Muskingum routing parameters
** over a single month and with a lower flow limit of 50,000 cfs per day.
**
JOBRTG      3      0      4      0.80      2  Bryan   Hemp
RFLOWS      1965      5      1965      5      1
RTYPES      MSK
QLOWER      50000.0
**
END

```

Table 4.3
DAYH Message DMS File for Example

WRAP-DAY MESSAGE FILE
Read JOBRTG record

```

-----
--- FLOW STATISTICS FOR GAGED FLOW INPUT DATA: ---
--- DAYS PER MONTH WITHIN FLOW RANGE ---
--- AVERAGE MONTHLY INFLOW ---
--- PEAK DAILY GAGED INFLOW PER MONTH ---
--- GAGED INFLOW PERCENTAGE OF GAGED OUTFLOW ---
--- AVERAGE MONTHLY OUTFLOW ---
---
--- UPSTREAM GAGE NAME Belton ---
--- UPSTREAM GAGE NAME Grang ---
--- DOWNSTREAM GAGE NAME Camer ---
-----

-----Belton-----| ----- Grang-----| -- Camer--|
YEAR MT N DAYHS AVG PEAK % AVG PEAK % AVG
1960 1 31 2582.8 5833.0 44.9 749.0 1517.0 13.0 5758.4
1960 2 29 1479.3 5350.0 37.3 627.8 2516.0 15.8 3964.5
1960 3 31 713.4 921.0 35.5 326.9 539.0 16.3 2008.9
1960 4 30 482.3 1300.0 37.6 209.6 828.0 16.3 1284.3
1960 5 31 304.4 709.0 35.2 125.2 427.0 14.5 865.2
...

-----
--- ROUTED HYDROGRAPHS ---
---
--- UPSTREAM GAGE NAME Belton ---
--- LAG 1.550 ---
--- ATT 1.000 ---
--- UPSTREAM GAGE NAME Grang ---
--- LAG 0.696 ---
--- ATT 1.000 ---
--- DOWNSTREAM GAGE NAME Camer ---
-----

-----Belton-----| ----- Grang-----| ----- Camer-----|
GAGED ROUTED GAGED ROUTED GAGED TOTAL
FLOW DNSTRM FLOW DNSTRM FLOW ROUTED
YEAR MT N DAYS
1960 1 1 2617.0 0.0 1347.0 409.5 6039.0 409.5
1960 1 2 1849.0 1178.4 1451.0 1378.6 8023.0 2557.1
1960 1 3 1720.0 2271.2 877.0 1276.5 6172.0 3547.7
1960 1 4 1842.0 1790.9 678.0 816.5 4827.0 2607.4
1960 1 5 5833.0 1774.9 738.0 696.2 4629.0 2471.2
1960 1 6 5347.0 3639.2 1136.0 859.0 7375.0 4498.2
1960 1 7 4284.0 5614.2 1517.0 1251.8 11449.0 6866.0
...

```

Routing Parameter Calibration Complete
JOBRTG complete

Read JOBRTG record
Routing Parameter Calibration Complete
JOBRTG complete

Table 4.4
DAYH Output DAY File for Example

Program WRAP-DAY (August 2015 Version) Output File

```

-----
---      OPTIMIZATION FOR ROUTING PARAMETERS      ---
---
---      UPSTREAM GAGE NAME          Belton        ---
---      UPSTREAM GAGE NAME          Grang         ---
---      DOWNSTREAM GAGE NAME        Camer         ---
-----

*** TEMPORAL RANGE FOR ROUTING CALIBRATION ***
START OF TEMPORAL RANGE      JANUARY, 1960
END OF TEMPORAL RANGE        DECEMBER, 1969
DAYS IN TEMPORAL RANGE      3653

*** FLOW RANGE FOR ROUTING CALIBRATION ***
GAGE NAME                    Belton          Grang
LOWER FLOW LIMIT              0.0            0.0
UPPER FLOW LIMIT 1000000000.0  1000000000.0
DAYS IN TEMPORAL AND FLOW RANGE 3653
LATERAL INFLOW ADJUSTMENT METHOD 0

*** ROUTING METHOD FOR OPTIMIZATION ***
GAGE NAME                    Belton          Grang
ROUTING METHOD                  Lag-Att

*** SEARCH SPACE FOR OPTIMIZATION ***
GAGE NAME                    Belton          Grang
LOWER LIMIT LAG or K          1.000          0.000
UPPER LIMIT LAG or K          3.000          2.000
LOWER LIMIT ATT or X          1.000          1.000
UPPER LIMIT ATT or X          0.25*LAG       0.25*LAG

*** RESULTS OF OPTIMIZATION CALIBRATION ***
GAGE NAME                    Belton          Grang
OPTIMIZED LAG or K            1.550          0.696
OPTIMIZED ATT or X            1.000          1.000

OBJECTIVE FUNC 5              188.9
LINEAR CORRELATION            0.95

COMPUTED LATERAL INFLOW VOLUME 3436395.0
PERCENT OF ACTUAL OUTFLOW VOLUME 47.42
ACTUAL LATERAL INFLOW VOLUME 3435653.0
PERCENT OF ACTUAL OUTFLOW VOLUME 47.41

*** STATISTICS OF GAGED FLOWS AND SIMULATED DOWNSTREAM HYDROGRAPH ***
*** WITHIN THE TEMPORAL AND FLOW RANGE ***
GAGE NAME                    Belton          Grang          Camer          SIMULATED
TOTAL VOLUME                  2793726.0      1017505.0      7246884.0      3810488.0
PERCENT OF OUTFLOW            38.6           14.0           100.0           52.6
MEAN                          764.8          278.5          1983.8          1043.1
STANDARD DEVIATION            2419.4         806.3          5141.3          2751.1
90TH PERCENTILE                1671.4         575.0          4389.6          2344.6

```

Table 4.4 Continued
DAYH Output DAY File for Example

75TH PERCENTILE	590.0	250.0	1696.0	884.8
50TH PERCENTILE	199.0	83.0	622.0	323.6
25TH PERCENTILE	64.0	36.0	261.0	121.2
10TH PERCENTILE	14.0	12.0	109.0	48.5

*** LINEAR CROSS-CORRELATION BETWEEN GAGED INFLOW AND GAGED OUTFLOW ***
 *** WITHIN THE TEMPORAL AND FLOW RANGE ***

GAGE NAME	Belton	Grang
TIME STEPS, OFFSET = 0	0.63	0.80
OFFSET = 1	0.80	0.82
OFFSET = 2	0.82	0.63
OFFSET = 3	0.65	0.43
OFFSET = 4	0.49	0.34
OFFSET = 5	0.38	0.32
OFFSET = 6	0.32	0.30
OFFSET = 7	0.28	0.28
OFFSET = 8	0.24	0.24
OFFSET = 9	0.20	0.20
OFFSET =10	0.16	0.18

```
-----
---  DIRECT SOLUTION FOR MUSKINGUM PARAMETERS  ---
---
---  UPSTREAM GAGE NAME          Bryan          ---
---  DOWNSTREAM GAGE NAME       Hemp           ---
-----
```

*** TEMPORAL RANGE FOR ROUTING CALIBRATION ***
 START OF TEMPORAL RANGE MAY, 1965
 END OF TEMPORAL RANGE MAY, 1965
 DAYS IN TEMPORAL RANGE 31

*** FLOW RANGE FOR ROUTING CALIBRATION ***
 GAGE NAME Bryan
 LOWER FLOW LIMIT 50000.0
 UPPER FLOW LIMIT 1000000000.0

DAYHS IN TEMPORAL AND FLOW RANGE 10
 LATERAL INFLOW ADJUSTMENT METHOD 0

*** RESULTS OF DIRECT CALIBRATION FOR MUSKINGUM GAGES ***

	GAGE	K	R
X = 0.00	Bryan	0.537	0.606
X = 0.10	Bryan	0.593	0.648
X = 0.15	Bryan	0.621	0.670
X = 0.20	Bryan	0.650	0.691
X = 0.25	Bryan	0.678	0.712
X = 0.30	Bryan	0.707	0.733
X = 0.40	Bryan	0.764	0.774
X = 0.50	Bryan	0.817	0.814

Table 4.4 Continued
DAYH Output DAY File for Example

```

*** STATISTICS OF GAGED FLOWS AND SIMULATED DOWNSTREAM HYDROGRAPH ***
*** WITHIN THE TEMPORAL AND FLOW RANGE ***
GAGE NAME           Bryan           Hemp           SIMULATED
TOTAL VOLUME        1138706.0       1138431.0       1138706.0
PERCENT OF OUTFLOW   100.0           100.0           100.0
MEAN                 113870.6        113843.1        113870.6
STANDARD DEVIATION   58996.6         67942.2         59020.0
90TH PERCENTILE     187174.0        193784.0        186662.8
75TH PERCENTILE     161341.8        170600.0        161022.3
50TH PERCENTILE     103438.5        110620.5        103438.5
25TH PERCENTILE     61414.8         56280.5         61095.2
10TH PERCENTILE     53911.5         40790.8         54422.7

```

Summary and Discussion of Routing Parameter Calibration

Routing parameters for selected river reaches are entered in *RT* records in a *SIMD* input DIF file for the control points defining the upstream ends of the reaches. A reach refers to the length of river between control points. Without routing and without reservoir storage, outflow from a river reach in a time step equals the inflow less channel losses. If stream routing parameters are assigned for a control point, routing computations are performed resulting in lag and attenuation of flow adjustments originating at or passing through the control point. Reservoir storage/operations affect stream flows in the simulation in a totally different manner and are modeled separately from the river reach routing discussed here.

Changes in stream flows due to diversions, return flows, refilling reservoir storage, and reservoir releases are routed in *SIMD*. Thus, time series of incremental flow adjustments rather than total stream flow hydrographs are routed.

The lag and attenuation routing method is designed specifically for routing daily flow changes in *SIMD* and is the recommended standard routing method for *SIMD* daily simulation applications. The Muskingum routing method covered in most hydrology textbooks is designed for computing instantaneous flows of a downstream flood hydrograph for a given upstream hydrograph. An adaptation of the Muskingum method was adopted in the early development of *SIMD*. Both the lag/attenuation and Muskingum adaptation are described and their comparative strengths and weaknesses discussed in the preceding Chapter 3.

Routing Parameters

With either the lag and attenuation routing method or adaptation of the Muskingum method, *SIMD* allow two sets of parameter values for each routing reach. LAGF and ATTF or MKF and MXF are applied to flow adjustments associated with flood control reservoir storage and releases. LAG and ATT or MK and MX are applied to all other flow adjustments. The routing algorithms and parameters are described in Chapter 3.

The parameters LAG or MK and parameters LAGF or MKF represent travel time which is typically smaller for flood flows than for low flows or normal flows. The parameters ATT or MX and parameters ATTF or MXF model attenuation effects that spread the flow out over time.

Routing parameters may be developed for every control point included in the *SIMD* simulation except the river system outlet. Alternatively, routing parameters may be provided for selected control points of which some may represent the aggregation of multiple river reaches.

Parameters may be calibrated for selected reaches and transferred based on judgment and availability information to other reaches. Parameter values for selected reaches determined by calibration computations may be transferred to other reaches based on reach lengths. Distance may serve as a surrogate for travel time in proportioning LAG, LAGF, MK, and MKF. The attenuation parameters ATT and ATTF, by definition, cannot be less than 1.0 day. Calibrated values of ATT and ATTF may be 1.0 day for many reaches. Likewise, the Muskingum MX and MXF varies much less than MK and MKF and may be assumed to be the same for multiple reaches. Parameter calibration is necessarily highly approximate.

Programs Daily Flows (DAY) and Daily Hydrographs (DAYH)

Programs *Daily Flows (DAY)* and *Daily Hydrographs (DAYH)* described in Appendices A and B, respectively, include routines to support routing parameter calibration which are described in the present Chapter 4. The more recently developed *DAY* methodology based on statistical analyses of flow changes is the recommended calibration computation option.

The calibration routine in the new *DAY* is based on statistical analyses of upstream and downstream changes in stream flow. The lags and attenuations associated with individual flow changes vary greatly between the numerous flow increases and decreases found in a record of observed daily stream flows. Criteria are specified in *DAY* for defining changes in stream flow. Flow change parameters including lags and attenuations are determined for numerous individual flow changes identified in the stream flow record. Statistical frequency metrics are computed for the lags and attenuations. Professional judgement is applied in assigning values to the parameters LAG, LAGF, ATT, and ATTF based on the results of the from the frequency analyses. For example, the median (50% exceedance frequency) quantities could be selected. In addition to supporting selection of specific values for the routing parameter, the statistical analyses provide insight regarding the variability and uncertainty inherent in calibration.

The fundamental concept of the calibration routine in *DAYH* is to determine values of routing parameters that will optimize an objective function formulated to minimize the difference between given and computed downstream hydrographs for a given upstream hydrograph. The routing parameters are determined in *DAYH* from these total flows and then applied in *SIMD* to rout adjustments or changes to the flows. Various options can be selected in applying the alternative variations of the optimization strategy.

Program *DAYH* determines values for the routing parameters LAG, ATT, LAGF, ATTF, MK, MX, MKF, and MXF for the single river reach defined by two control points. The optimization routines also allow simultaneous calibration of routing parameters for multiple reaches defined by the same downstream control point but different upstream control points.

The *DAYH* calibration may use the entire period-of-analysis reflected in the flow sequences found in the DCF file or any user-defined segment thereof. Upper and lower limits defining a range of flows to be used for the calibration may also be specified. The spread of the related flows generated by the lag and attenuation parameters can be reduced by adopting the default limit (Equation 4.13) or by setting a user specified limit.

The automated optimization option is based on the model-user's choice of objective function F_1 , F_2 , F_3 , F_4 , or F_5 (Equations 4.2, 4.3, 4.7, 4.8, or 4.9). The results of the calibration consist of optimal values for the routing parameters along with the corresponding value for the objective function. An optional table may be developed tabulating values for each of the five alternative objective functions for a user-specified set of values for the routing parameters.

DAYH output tables also include statistics which are provided for general information in better understanding flow characteristics and calibration results. Statistics are tabulated for the flows at the upstream and downstream control points. Lateral inflow flow volumes are shown. Serial correlation coefficients for a range of lags are listed. The Muskingum parameter K is related to travel time or the lag between outflows and inflows.

CHAPTER 5 RESERVOIR OPERATIONS DURING FLOODS

Flood control reservoirs are modeled in *SIMD* as *FR* and *FF* record water rights. Operation of multiple-reservoir systems with any number of reservoirs may be based on flood flow limits at any number of downstream control points as specified by *FF* records. Storage in individual reservoirs may also be governed by storage versus outflow relationships defined by *FV* and *FQ* records. Storage versus outflow tables (*FV/FQ* records) can also be used to simulate surcharge storage and associated spills over uncontrolled (ungated) spillways for reservoirs that are not necessarily operated for flood control. The daily time step features described in Chapter 3 facilitate simulation of flood control gate operations and spills over uncontrolled spillways.

Most of the tables created with program *TABLES* are generally applicable to organizing *SIMD* results irrespective of whether flood control operations are included in the simulation. *TABLES* also has options for frequency analyses of annual peak flow and storage and economic damage analyses designed specifically for flood studies.

Operation of Flood Control Reservoirs

Most of the large flood control reservoirs in Texas and throughout the United States were constructed and are operated by the U.S. Army Corps of Engineers [12]. Exceptions include International Amistad and Falcon Reservoirs on the Rio Grande operated by the International Boundary and Water Commission, the Tennessee Valley Authority System, and multiple-purpose reservoirs constructed by the Bureau of Reclamation in the western states for which the Corps of Engineers is often responsible for flood control operations. Most of the flood control storage capacity in Texas is contained in multiple-purpose federal projects that also provide water supply and recreation and in some cases hydroelectric power.

Releases from flood control reservoirs occur through spillways and other outlet structures that may be either uncontrolled with no gates or controlled by people opening and closing gates. *SIMD* can simulate either gated or ungated structures. The Natural Resource Conservation Service has constructed numerous flood control dams with ungated outlet structures in rural watersheds. The numerous small flood retarding structures constructed by local entities for stormwater management in urban areas are also typically ungated. Water supply reservoirs with no designated flood control pools pass high flows over spillways. Without gates, outflows are governed by the stage-discharge characteristics of the outlet structures. The large federal projects typically have gated outlet structures allowing people to make operating decisions. Uncontrolled spillways with a crest elevation at the top of the controlled storage may pass extreme flood flows while other gated outlet works are used for controlled releases from the conservation and flood control pools. The following discussion focuses on operations of reservoirs that are equipped with gated outlet structures that allow people to control releases.

Reservoirs may be operated solely for flood control, for only conservation purposes, or for both flood control and conservation. Conservation purposes include municipal and industrial water supply, agricultural irrigation, hydroelectric power, recreation, and environmental protection or enhancement. Multiple-purpose operations are based on dividing the storage capacity into conservation and flood control pools separated by a designated top of conservation pool elevation

as illustrated by Figure 5.1. The top of the conservation pool is the bottom of the flood control pool. The allocation of storage capacity between pools may be constant or vary seasonally. The conservation pool storage contents are maintained as close to capacity as inflows and water demands allow. The flood control pool remains empty except during and following flood events.

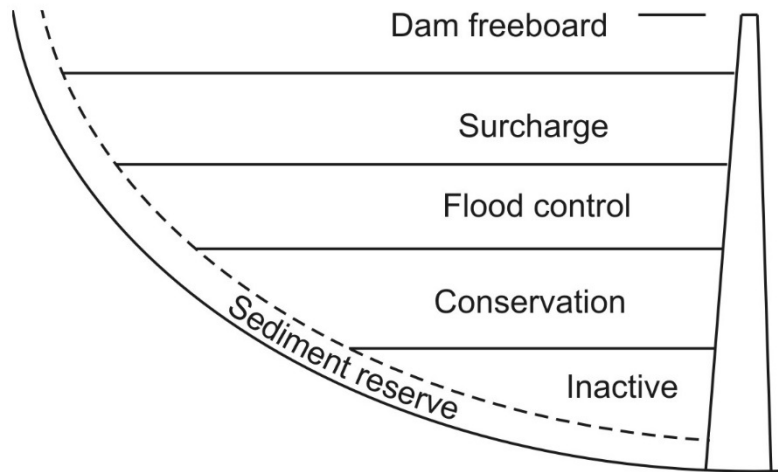


Figure 5.1 Reservoir Pools

Flood control operations are based on minimizing the risk and consequences of making releases that contribute to downstream flooding. Maximum allowable flow rates and stages at downstream control points are set based on bank-full river flow capacities, stages at which significant damages occur, environmental considerations, and/or constraints such as inundation of road crossings or other facilities. Releases are made to empty flood control storage capacity as quickly as possible without contributing to stream flows exceeding specified maximum allowable flow levels at the downstream gaging stations. When a flood occurs, the spillway and outlet works gates are closed. The gates remain closed until a determination is made that the flood has crested and flows are below the target levels specified for each of the gaged control points. The gates are then operated to empty the flood control pool as quickly as possible without exceeding the allowable flows at the downstream locations. The pool is emptied in preparation for the next storm producing flood inflows which will occur at some unknown time in the future.

Reservoir operations are based on flow limits at downstream locations as long as the flood control pool is not overtopped. During extreme flood events exceeding the flood storage capacity, flood waters may encroach into surcharge storage. With the flood control pool capacity exceeded, releases causing damages downstream are required to prevent the reservoir stage from exceeding a maximum design water surface level set based on protecting the structural integrity of the dam. If flood waters are expected to rise above the top of flood control pool, emergency operating procedures are activated with releases through gates determined based on inflows and storage levels [12]. Alternatively, uncontrolled spills may flow through ungated spillways.

In many cases, the allowable non-damaging channel capacity at a given river location is constant regardless of the volume of water in storage. However, operating rules may be formulated with the allowable flow rates at one or more operational control points varying depending upon the

volume of water currently stored in the flood control pools. This allows stringently low flow levels to be maintained at certain locations as long as only a relatively small portion of the flood control storage capacity is occupied, with the flows increased to a higher level, at which minor damages could occur, as the reservoirs fill.

The gaged operating control points governing reservoir release decisions may be located significant distances below the dams. Uncontrolled local inflows from watershed areas below the dams increase with distance downstream. Thus, the impacts of reservoirs on flood flows at downstream locations decrease with distance downstream.

A reservoir may have one or more operational control points that are related only to that reservoir and several other control points that are shared with other reservoirs. For example, in Figure 5.2, gaging station 3 is used as a control point for both Reservoirs A and B, and gage 4 controls releases from all three reservoirs. Multiple-reservoir release decisions are typically based on maintaining some specified relative balance between the percentage of flood-control storage capacity utilized in each reservoir. For example, if unregulated flows are below the maximum allowable flow rates at all the control points, the reservoir with the greatest amount of water in storage, expressed as a percentage of flood control storage capacity, might be selected to release water. Various balancing criteria may be adopted. Flows at downstream control points depend upon releases from all reservoirs and runoff from uncontrolled watershed areas below the dams.

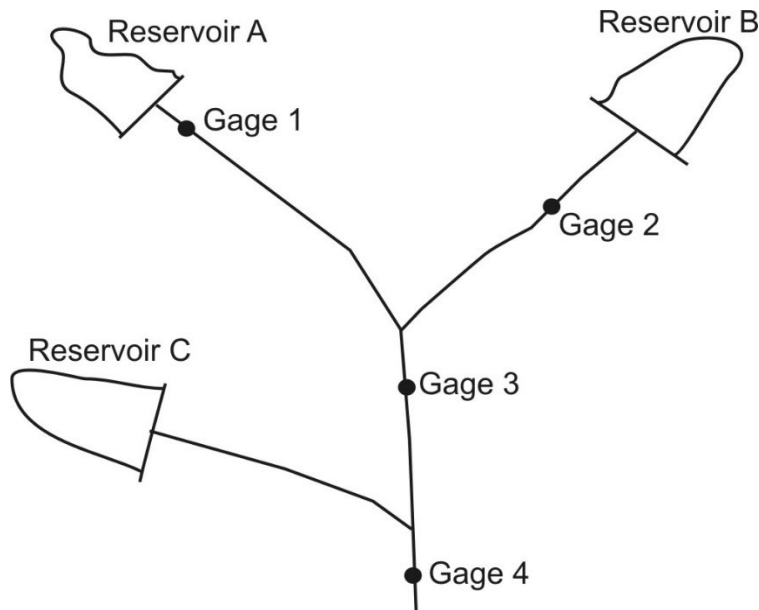


Figure 5.2 Multiple-Reservoir System Flood Control Operations

In order to minimize the risk of reservoir releases contributing to downstream flooding, operators are cautious about closing gates too late or making releases too soon. Outlet gates are opened only after some degree of confidence that flows are receding. Uncertainties regarding inflows from watershed areas below the dams and flow attenuation and travel times from the dams to the downstream control points are a key aspect of operations. Water released from a dam today may reach downstream control points several days from now. Releases combine with future unknown

unregulated local inflows below the dams. Additional unexpected rainfall may occur during the time before water released from a dam reaches downstream sites on the river. Forecasting of future flows over the next several days is difficult. These uncertainties inherent in actual reservoir flood control operations are also important in *SIMD* modeling of operations.

Computer Programs, Data Files, and Input Records

The flood control reservoir *FR*, flood flow *FF*, flood volume *FV*, and flood outflow *FQ* records described in Chapter 4 of the *Users Manual* are the only *SIMD* input records designed specifically for flood control. *FR* and *FF* records are used to model reservoir operations for flood control analogously to applying *WR*, *WS*, *OR*, and *IF* records to model operations for water supply, hydropower, and environmental instream flow requirements. The WRAP program *SIM* simulates water rights described by *WR*, *IF*, and other supporting input records, which are described in detail in the *Reference* and *Users Manuals*. *SIMD* has *FR* record rights as well as the basic *WR* and *IF* record rights. The auxiliary records that may be attached to the *WR* and *IF* records to activate target setting options are also applicable to setting the *FF* record flood flow target.

Reservoir outflows may also be specified as a function of storage. *FV* and *FQ* records provide a table of reservoir storage volume versus outflow rate that is linearly interpolated in *SIMD* in the same manner as *SV/SA*, *PV/PE*, and *TQ/TE* record tables input to either *SIM* or *SIMD*. The *FV/FQ* table is interpolated to determine outflow for a given storage volume.

SIMD creates an optional output file with the filename extension *AFF* with annual series of peak flood flows and storages. The maximum naturalized flow, regulated flow, and storage volume are listed for each year of the simulation at specified control points. The *SIMD* *AFF* file is read by *TABLES* to perform flood frequency and damage analyses specified by a *7FFA* record.

The tables created by *TABLES* to organize simulation results are generally applicable either with or without consideration of flood control. The *7FFA* record flood frequency analysis table is the only *TABLES* option designed specifically for flood control. Frequency tables are developed for reservoir storage, naturalized flow, and regulated flow based on applying the log-Pearson type III or log-normal probability distribution to the annual series. Economic damages interpolated from a discharge or storage versus damage table may also be included in the frequency table. The *7FFA* record is included in Appendix B and discussed later in this chapter.

Simulation of Reservoir Operations During Floods

Each reservoir in a *SIMD* simulation may include either, both, or neither of the following two types of flood mitigation operations. The second type is applicable to water supply reservoirs with no designated flood control pools as well as to flood control reservoirs.

1. *FR* and *FF* records control reservoir release decisions based on stream flows at downstream control points. Releases from *FR* record reservoirs are based on emptying controlled flood control pools as quickly as possible without contributing to flows exceeding maximum limits within the forecast period specified by *FF* records at the control point of the reservoir and at any number of downstream control points. Reservoirs may be operated individually or as one or more multiple-reservoir systems. The *FR/FF* record options simulate reservoirs with gated outlet structures with releases controlled by people operating gates.

2. A *FR* record and pair of *FV* and *FQ* records simulate a fixed storage volume versus outflow rate relationship. The volume released from the reservoir in a given day depends on the mean storage volume during that day determined by linear interpolation of the *FV/FQ* record storage-outflow table. Ungated outlet structures or fixed gate openings are modeled.

The term "*controlled*" flood control operations is used here to refer to people opening and closing gates on outlet structures to empty designated flood control storage capacity without contributing to downstream flooding as defined by flow limits on flood flow *FF* records. "*Uncontrolled*" flood control operations refers to ungated outlet structures where flows through the structure depend only on the storage contents of the reservoir as defined by *FV/FQ* records. Gated structures with a fixed non-varying gate opening are also modeled with *FV/FQ* records.

Controlled flood control pools defined *FR* and *FF* records can be operated as individual reservoirs or multiple-reservoir systems. Uncontrolled surcharge pools defined by *FR* and *FV/FQ* records are always operated individually without multiple-reservoir system interconnections. A particular reservoir may include either or both types of operations. Releases from a controlled flood control pool may be controlled by both *FF* and *FV/FQ* record specifications, with the daily release being constrained to the lesser of the two releases computed based on the *FR/FF* versus *FV/FQ* records. Reservoirs may be operated in *SIMD* for conservation purposes only with no flood control features at all or may include both conservation and flood control features.

Flood control reservoir operations are treated in *SIMD* as a type of water right. In WRAP terminology, a water right is a set of water control requirements and associated reservoir facilities and operating rules. Flood control rights activated by pairs of *FR* and *WS* records are simulated along with all the other water rights activated by *WR* and *IF* records. Any number of *FR*, *WR*, or *IF* record rights may be associated with the same reservoir with the use of *WS* records.

A flood control *FR/WS* record water right is equivalent to two *WR/WS* record water rights. Storage and release functions are handled separately, with storage occurring before release in the simulation priority sequence computations. The storage component of a flood storage right is equivalent to a *WR/WS* record type 1 right that refills storage but has no diversion. The flood release is modeled as a water right at the reservoir with a demand determined based on available channel capacity and no reservoir refill capacity. The flood release right is analogous computationally to monthly rule curve spills specified by a monthly storage *MS* record.

One and only one storage *WS* record must be provided with each *FR* record. Multiple successive *FR* records can share a single *WS* record placed after the *FR* record set. *WS* record fields 3, 7, and 11 are ignored on the *WS* record. Auxilliary records associated with water right *WR* records such as *TO*, *SO*, *TS*, *PX* records are not used with a *FR* record.

The sub-monthly time step features of *SIMD* are applied in modeling reservoir operations for flood control. Relatively small computational time steps are required to accurately model flood control operations due to the great fluctuations in flow rates over short time spans that occur during floods. A daily interval is commonly used in flood studies for large river/reservoir systems. However, small systems may require smaller time steps. Discussions in this chapter are based on the assumption that a daily computational time interval is adopted.

Reservoir Pools

In *SIMD*, a reservoir consists of any or all of the four pools shown in Figure 5.3. *SIM* includes only the bottom two pools. In either *SIM* or *SIMD*, inactive and conservation pool storage capacities are specified in storage *WS* records associated with water right *WR* records. Additionally, *SIMD* allows surcharge and/or flood storage to be specified by a pair of *FR* and *WS* records. The *SIMD* uncontrolled and controlled zones of the flood control pool in Figure 5.3 represent the surcharge and flood control pools of Figure 5.1.

The reservoir pools are vertical storage zones designated by the following total cumulative storage volume capacities entered on *WS* and *FR* records.

- INACT – Total volume below top of inactive pool (*WS* record field 7).
- WRSYS(SR,3) – Total volume below top of conservation pool (*WS* record field 3).
- FCBOTTOM – Total volume below bottom of flood control pool (*FR* record field 10) which is normally but not necessarily the same as WRSYS(SR,3).
- FCGATE – Total volume below bottom of uncontrolled flood control pool which is also the top of the controlled flood control pool (*FR* record field 9)
- FCTOP – Total volume below top of flood control pool (*FR* record field 8)

In the *SIMD* simulation, a reservoir may contain any combination of one or more pools illustrated in Figure 5.3 and defined as follows.

Flood Control Pool.– A flood control pool is defined by storage volumes FCTOP and FCBOTTOM entered in *FR* record fields 8 and 10. The flood control pool may include zones with outflows through controlled (gated) and/or uncontrolled (ungated) outlet structures. The uncontrolled surcharge storage capacity and the controlled flood control pool are separated by the storage level FCGATE entered in *FR* record field 9.

Uncontrolled Flood Control Storage.– Releases are specified as a function of storage level by a storage versus outflow table provided on *FV* and *FQ* records. *FV/FQ* records are designed for modeling outflow from an individual reservoir governed by the fixed hydraulic design of outlet structures rather than by people operating gates.

Controlled Flood Control Storage.– Controlled means that releases are through gated outlet structures with release decisions based on maximum allowable flows at downstream control points specified on *FF* records. Any number of reservoirs may be operated as a system to control river flows at any number of downstream control points. Flows during the current day and forecast period are considered. Releases from controlled flood control pools optionally may also be constrained to not exceed the maximum outlet release capacity defined by *FV* and *FQ* records.

Conservation Pool.– Releases or withdrawals from the conservation pool defined by a *WS* record are for water supply diversion, hydropower, and instream flow requirements.

Inactive Pool.– The only way that water can be removed from the inactive pool defined by a *WS* record is through evaporation occurring while the conservation pool is empty.

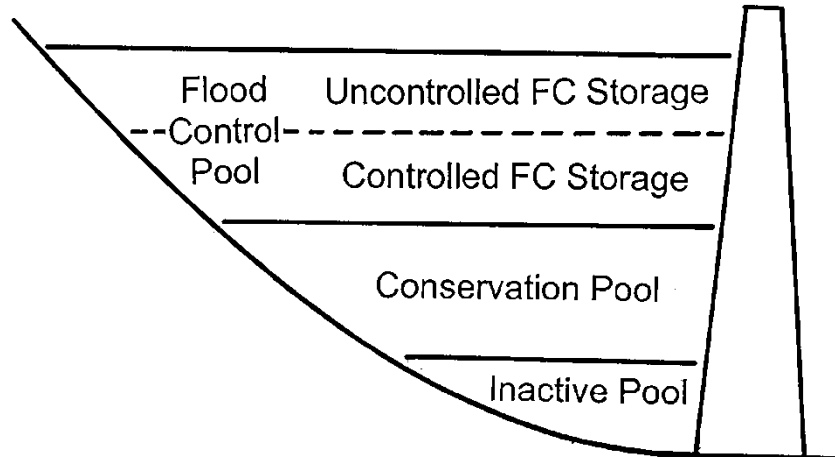


Figure 5.3 Reservoir Pools Defined by *SIMD WS* and *FR* Records

A single *WS* record must follow each *FR* record, or optionally follow a group of *FR* records for the same reservoir. The *WS* record is necessary to provide a reservoir identifier in *WS* record field 2. *WS* record fields 3, 7, and 11 are relevant only for conservation reservoirs and are therefore ignored when a *WS* record is read following a *FR* record or a group of *FR* records. The default setting for *WS* record field 8 is to assume the flood control pool is empty at the beginning of the simulation.

Uncontrolled releases are modeled with *FV/FQ* record tables of storage contents versus daily release volume. Releases controlled by gated outlet structures are modeled by *FF* records. These surcharge and gate releases depend upon the storage content in the reservoir after conservation storage operations are completed. Releases from storage capacity above the *FCBOTTOM* are in addition to those releases that may be made from the conservation pool. *FCTOP*, *FCGATE*, and *FCBOTTOM* are specified on the flood reservoir *FR* record.

First the volume of water available for storage and/or release is determined and then releases are determined as follows. In the following three-step explanation of the rules governing computation of releases from the flood control pool, *FCV* denotes the total volume of water available for flood storage and/or release for a particular reservoir in a particular day of the simulation. The total release is the summation of releases computed in the three steps.

- Step 1. If *FCV* is above *FCGATE*, a release component is computed based on linear interpolation of the table of storage volume versus daily outflow volume provided on *FV* and *FQ* records. This release is not allowed to exceed the release volume required to reduce the storage content to *FCGATE*. If no *FV/FQ* records are provided, the release is the outflow required to reduce the storage content to *FCGATE*.
- Step 2. If *FCV* is large enough to overtop the top of flood control pool *FCTOP* after the Step 1 (or Step 2 if no Step 1) computations, an additional outflow (flood release) for the day occurs as necessary to reduce the storage content to *FCTOP*. Outflow equals inflow to the extent necessary to limit the computed storage level to not exceed *FCTOP*.

Step 3. If FCV after considering Steps 1 and 2 is above FCBOTTOM and at or below FCGATE, a release is computed as the minimum of the following quantities.

- The total volume of water available for storage in the flood control pool above FCBOTTOM and/or release therefrom.
- The downstream channel capacity computed based on information provided on flood flow *FF* records less releases from Steps 1 and 2.
- The release capacity at the dam computed as FCMAX from *FR* record field 7 less any other conservation or flood control releases through the dam. This quantity is not computed if the field for FCMAX on the *FR* record is zero or blank.
- The outlet structure capacity computed by interpolating the table of storage volume versus daily outflow volume provided on *FV* and *FQ* records. This quantity is not computed if *FV/FQ* records are not provided or if the parameter in *FQ* record field 2 is activated to limit use of the *FV/FQ* records to storage levels above FCGATE.

Thus, the reservoir flood control pool in *SIMD* is divided into *controlled* and *uncontrolled* storage capacity as defined by storage levels entered on the *FR* record. Both portions of the flood control pool are optional. Releases from the lower controlled portion of the flood control pool are constrained by stream flow limits entered on *FF* records and outlet capacities defined by *FV/FQ* records. Releases from the upper uncontrolled portion are defined completely by the *FV/FQ* record storage-outflow table. For a reservoir with no outlet structure gates, the entire *SIMD* flood control pool is composed of the uncontrolled portion of Figure 5.3. For a reservoir with gated outlets, the top of the controlled portion of the flood control pool in Figure 5.3 refers to the storage level above which outflows are controlled only by storage contents as defined by the *FV/FQ* record storage-outflow table without consideration of stream flows at downstream locations.

As illustrated by Figures 5.1 and 5.3, reservoir operators often use the term "*top of flood control pool*" somewhat differently than the *SIMD* model to refer to only the controlled flood control storage. The term *surcharge* storage is applied to uncontrolled storage space above the flood control pool. The *SIMD* uncontrolled portion of the flood control pool may be used to model surcharge storage controlled only by ungated emergency spillways or by limited outlet structure outflow capacity.

Reservoir Operations

Reservoir operations for either flood control or conservation purposes in *SIM* or *SIMD* consist of two separate operations: (1) storing inflows and (2) making releases. Filling storage and making releases are two related aspects of reservoir operations that are handled differently in defining operating rules and performing simulation computations.

From the perspective of storing inflows, the total storage capacity at the top of conservation pool and top of flood control pool are specified in *WS* record field 3 and *FR* record field 8, respectively. Storage is filled to these levels by *WR* and *FR* record rights, respectively. If a conservation pool is not full when a *FR* record impounds flood flows, the empty conservation space is filled as the storage level rises into the flood control pool. Any number of *FR/WS* and *WR/WS* record rights with different storage capacities may be assigned to the same reservoir.

Junior rights must have storage capacities equaling or exceeding senior rights in the same reservoir. As *WR* or *FR* record rights are considered in priority order, reservoir storage is filled up to the specified storage capacity subject to the limitation of available stream flow.

Option switch FCDEP in *FR* record field 6 controls whether downstream control points are considered in computing the amount of stream flow available for filling flood control pools. With the default FCDEP option, the control point flow availability array is applied in the conventional manner to determine the amount of flow available for storage a flood control pool. The alternative FCDEP option is to store all regulated flow at the control point of the dam. With either option, filling flood control storage may be affected by senior water rights. Within each time step, each water right is simulated in priority order. Flood control *FR* record rights will normally be junior to water right *WR* record and instream flow *IF* record rights.

The top of conservation pool shown in Figure 5.3 may vary between months of the year defining a seasonal rule curve operating plan. Thus, portions of the total storage capacity are reallocated between the conservation and flood control pools on a monthly or seasonal basis. Monthly varying conservation pool capacities are specified on monthly storage limit *MS* records described in the *Users Manual*.

Releases from conservation pool storage depend on operating rules specified by *WR*, *IF*, *WS*, and supporting records as described in the *Reference* and *Users Manuals*. Controlled releases from flood control pool storage are governed by operating rules defined by parameters entered on *FR* and *FF* records. Uncontrolled outflows through ungated outlet structures or gated structures with a fixed non-varying opening are specified by *FR*, *FV*, and *FQ* records.

Reservoir outflows associated with *FR* record rights model flows through spillways and other outlet structures that may be either uncontrolled (ungated) or controlled by opening and closing gates. *SIMD* computational algorithms for determining outflows are totally different for controlled versus uncontrolled flood control storage (with versus without operator decisions). Modeling uncontrolled outlet structures is much simpler than modeling operations of reservoirs with gated structures controlled by people. Outflows from an uncontrolled outlet structure depend only on storage and flow conditions at the reservoir for the current day. Operating rules for controlled flood control pools may depend upon storage in multiple reservoirs and flows at multiple control points during the current day and each day of various forecast periods.

Routing Flows Through River/Reservoir Systems

The *SIMD* algorithms for routing flood flows through reservoirs with either ungated or gated outlet structures are described in the following sections of this chapter. Routing through uncontrolled reservoir pools with ungated outlet structures is performed in two steps: (1) the inflow volume available for storage is determined and (2) the outflow is determined based on a storage-outflow relationship. Routing through flood control pools controlled by gated outlet structures is based on more complicated operating rules discussed later.

SIMD algorithms applying the attenuation and lag method and Muskingum adaptation for routing flow changes through river reaches are described in Chapter 3. The *SIM/SIMD* linear channel loss equation is described in the *Reference Manual*. The routing and channel loss

methodologies are used to adjust flows at downstream control points for the effects of stream flow depletions associated with storing flood waters and the effects of subsequent releases from flood control storage. Flow routing simulates lag and attenuation. Storing and subsequent releasing of inflows to flood control pools may affect regulated flows at downstream control points in future days as well as in the same day that the flood flows are stored or released.

Water rights are simulated in a priority loop that minimizes the effects of junior rights on senior rights. As discussed in Chapter 3, lag/attenuation or Muskingum routing of certain flow adjustments occurs before simulating individual water rights. Routing flow changes associated with individual *WR* record rights may optionally occur within the priority loop computations using *JU* record *WRMETH* option 2 or *WRF CST* option 2. The *SIMD* algorithms implementing the lag/attenuation and Muskingum routing options are designed to prevent stream flow depletions and other actions by junior water rights occurring in the current day from impacting senior rights in subsequent days.

The *JU* record *WRMETH* switch applies the same two options to flood control *FR* record rights as is applied to *WR* record rights for organizing the routing of flow adjustments from one day to the next. Option 2 performs the routing of flow adjustments totally within the priority-based water rights simulation loop. Impacts of junior flood control operations on senior *WR* record water rights are minimized. Option 1 places flow adjustments routed from the preceding day at the beginning of the next-day simulation before the water rights loop. Senior rights may be affected by flood control activities occurring during preceding days. For example, *WR* record water supply diversion rights will have access to stream flows released from flood control pools. Storing flood waters may affect storage levels in conservation pools regardless of placement of routed flow adjustments in the simulation process.

Forecasting of Future Flows

The *SIMD* forecasting strategy previously described in Chapter 3 and outlined again in Table 5.1 is based on a preliminary simulation over a forecast period to forecast flows followed by a final complete simulation for a single time step. This two-simulation process is repeated at each time step. Each water right may be assigned a different forecast period FF_P in the input data.

Assuming forecasting is specified for at least one *WR* or *FR* record right, a preliminary simulation at the beginning of each time step provides daily water availability and regulated flow arrays covering the simulation forecast period F_P for use during the second normal simulation. The only results saved from the initial simulation at each time step are:

- Array of flow availability for each *WR* record water right as discussed in Chapter 3
- array of regulated flows without releases from flood pools for each flood flow *FF* record control point

FF_P is the number of days, current and future, considered in the simulation in making reservoir flood control operating decisions. As discussed in Chapter 3, the default FF_P is automatically determined by *SIMD* from the *RFA* array as the flow time between a *FR* record reservoir and *FF* record control point. The optional forecast period in *FF* record field 5 places a maximum limit on FF_P . For flood control operations, for each day of the normal simulation,

regulated flows for FF_P days at the FF record control points are obtained from the array of regulated flows developed during the preceding forecast simulation.

Table 5.1
Simulation of Controlled Reservoir Flood Control Operations

Preliminary Forecast Simulation.— At the beginning of each time step (day), an initial simulation is performed for the forecast period with storage of flood waters but without gate releases from flood control pools. This initial simulation provides forecasted estimates of future regulated flows without releases from controlled flood control pools that are used to determine remaining non-damaging flow capacities at FF record control points.

Final Normal Simulation.— The simulation is repeated for one time step (day) with all features activated. Flood control operations are modeled as follows.

1. For multiple-reservoir systems, reservoirs are prioritized based on beginning-of-day storage and parameters from the FR records. Each individual reservoir is assigned a relative priority, which may vary daily, that governs sequencing of operating decisions.
2. Flood waters are stored as each FR record right is considered in priority order. A yes or no decision is made regarding closing the outlet gates controlling the flood control pool.
 - a. Flows at each pertinent FF record control point located at or downstream of the dam are checked. A flood is declared to be in progress or imminent if the regulated flow in the current day or flow estimate in any day of the forecast period at one or more control points exceeds the flow limit from the FF record.
 - b. If a flood is declared, flood gates for the FR record right are completely closed, filling storage in the standard manner applied for all WR and FR record rights.
3. Flood control pools are emptied as flood waters recede. A decision is made regarding whether or not to release water and, if so, the amount to be released.

As the flood control reservoirs are considered in turn, the release from each reservoir is based on the minimum flood flow capacity determined based on FF record limits for flows at each pertinent control point for the current day and each future day of the forecast period and releases from other reservoirs. The flow capacity is reduced for releases made by preceding flood control reservoirs.

Uncertainties and inaccuracies in forecasting future flow conditions are a major concern in both real-world reservoir operations and modeling of reservoir operations. Some time lag, perhaps many days, may be required for the effects of reservoir storage and releases to reach downstream control points. Storing flood water in a reservoir today may affect flows at downstream locations over the next several or perhaps many days. Flood hydrographs attenuate as flows pass through river systems. The flows at a control point include local unregulated flows entering the river below dams as well as regulated releases from reservoirs located upstream.

Flood control operating procedures are designed to maintain flood control pools as empty as possible to provide storage capacity for future floods of unknown magnitude and timing while making no releases that contribute to flooding. The objectives are (1) to close gates in a timely manner at the beginning of a storm to store flood waters to minimize flooding and (2) to empty flood control pools expeditiously as flood flows recede without reservoir releases contributing to flows exceeding specified maximum non-damaging flow limits.

By adopting long forecast periods, the *SIMD* modeling approach generally provides a conservatively high estimate of the amount of water to be stored in flood control pools to assure that flow amounts above the flow limits during the forecast period are minimized to the extent possible. Due to approximations related to forecasting and routing, water may be stored in greater quantities and longer than absolutely necessary. However, future days extending past the forecast period are not considered in reservoir operating decisions. Routed reservoir releases could contribute to flooding at downstream control points in future days after the end of the forecast period. Approximations related to imperfect forecasting and routing are an issue in modeling of reservoir operations as well as in actual real-world reservoir operations.

Controlled Reservoir Flood Control Operations

The *SIM/SIMD* simulation process outlined in Figure 2.2 of the *Reference Manual* is organized based on a water rights priority loop nested within a period loop. A two-phase simulation strategy for incorporating forecasting in *SIMD* is outlined in Table 3.4 of the preceding Chapter 3. Flood control operation features of *SIMD* defined by sets of *FR* and *FF* records are embedded within the overall simulation process as outlined in Table 5.1.

WR, *IF*, and *FR* record rights are considered in priority order in the water rights computational loop. The priorities on the *FR* records used to define flood control operations should normally be junior to all of the *WR* and *IF* record water rights in the dataset modeling the river/reservoir system. *FR* record rights have two priorities, one for storing flood flows and another for subsequent releasing of the flood water from the flood control pools. Multiple-reservoir system operations are based on varying release priorities between reservoirs based on their relative percentage depletion of storage capacity which may change daily.

Any number of reservoirs identified by *FR* records may be operated based on maximum non-damaging flow limits specified by *FF* records at any number of control points. Reservoirs with gated outlet structures are operated based on flow limits specified by *FF* records at the control points of the reservoirs and at downstream control points in the current day and all the days during the forecast period. *FR* and *FF* records define operating rules as follows.

- Flood flow *FF* records and supporting records set flow targets at pertinent control points defining the limits above which significant flooding occurs.
- Flood control *FR* records define rules for filling and emptying reservoirs that are based on the flow limits set by the *FF* records.
 1. Gates are closed whenever a flood is underway or imminent as defined by flows exceeding the limits set by the *FF* records.
 2. Flood control pools are emptied expeditiously without releases contributing to flows exceeding the limits set by the *FF* records.

Simulation of reservoir operations for flood control consists of the two separate tasks of storage and release that may occur at different points in the water rights priority loop.

1. Gates are closed if a flood is determined to be underway or imminent based on flows at *FF* record control points in the current day or forecast period. Reservoir storage is filled subject to the controlled flood control capacity and flow availability determined in the manner generally applied to both *FR* and *WR* record rights. Storage in each reservoir is filled in a sequential order defined by priorities and multiple-reservoir ranking indices.
2. Releases are based on emptying flood control pools as expeditiously as practical without contributing to river flows exceeding *FF* record flow limits. Release decisions are based on flow estimates considering the current day and future days comprising the forecast period, which are subject to forecasting uncertainties. Operations are governed by *FR* record multiple-reservoir system operating rules and *FF* record flow limits at any number of control points.

Outlet Capacity Defined by Storage-Outflow *FV/FQ* Records

The table defined by a pair of *FV* and *FQ* records represents the relationship between storage volume and outlet discharge capacity for channels or ungated structures or for structures with gates fully open or at a specified fixed opening. Routing of flood flows based on *FV/FQ* records is applicable to individual reservoirs, without consideration of multiple-reservoir systems. *FV/FQ* record outflows are governed by reservoir storage contents and inflows in the current day.

The outlet structures of a flood control reservoir or flood retarding dam may be uncontrolled with no gates and thus no gate operations by people. Outflows are controlled by the hydraulic design of the outlet structure with no release decisions by human operators. The hydraulics are modeled with a storage-outflow table provided on *FV* and *FQ* records. Forecasting and *FF* records are not relevant for uncontrolled outlet structures.

FV/FQ records are also used to model the outlet capacity for fully open or fixed-opening gated outlets. The *FV/FQ* record discharge capacities may provide upper limits on releases from controlled (gated) flood control pools operated based on *FF* record downstream flow criteria.

Reservoirs with controlled flood control pools and/or conservation pools with releases through gated outlet structures may also have uncontrolled spillways. Uncontrolled spillways or gated spillways operated in accordance with emergency flood regulation plans may control surcharge storage in reservoirs that also have controlled flood control storage. Spills may also be routed through an uncontrolled spillway with a crest elevation at the top of conservation pool at a water supply only reservoir that has no flood control storage. Surcharge storage in water supply reservoirs, without designated flood control pools, occurs incidentally due to the limited outflow capacity of the spillway. These situations may also be modeled in *SIMD* with *FV* and *FQ* records.

The storage-outflow relationship provided by a pair of *FV* and *FQ* records are applied differently depending on whether the storage level rises above *FCGATE*, which is defined in Table 5.3. In the uncontrolled pool above *FCGATE*, releases depend solely on the *FV/FQ* record storage-outflow relationship. In the controlled pool below *FCGATE*, the *FV/FQ* record storage volume versus outflow capacity (volume/day) relationship provides a maximum limiting release capacity. Releases may be less than this upper capacity limit depending on *FR/FF* record operating rules.

With a set of *FV* and *FQ* records connected to a *FR* record right, a release rate from the uncontrolled pool or release capacity limit for the controlled pool is determined as the outflow computed by linear interpolation of the table of storage volumes versus outflow volume/day. As the *FR* record right is considered in the water rights priority loop, routing flow through the reservoir consists of the following two tasks.

1. The inflow volume available to fill storage is determined in the standard manner applied to all *FR* and *WR* record rights.
2. Outflows are computed by linear interpolation of the *FV/FQ* record storage-outflow table. An iterative algorithm determines the outflow during the day based on averaging beginning-of-day and end-of-day storage volumes.

Flood Flow Limits Defined by *FF* Records

A *FF* record is required for each control point location at which a flood flow limit is set. The *FF* record target represents a maximum non-damaging river flow level upon which flood control operations are based. A *FR* record reservoir is operated based on a particular *FF* record if the *FF* record control point is located downstream of the reservoir. The operation of a *FR* record reservoir may consider any number of *FF* record flow limits. Any number of reservoirs may consider the same *FF* record flow limit. Chapter 4 of the *Users Manual* provides instructions defining variables entered in each of the fields of the *FF* record. The input data are also listed below.

Table 5.2
Flood Flow *FF* Record Input Variables

Field	Description
1	Record identifier (FF)
2	Control point identifier
3	Annual flood flow limit volume
4	Monthly distribution identifier, default = uniform
5	Forecast period, default = 0 (no forecast)
6	Flood index to connect to <i>DI/IS/IP</i> record

A *FF* record monthly flood flow limit is set similarly to an *IF* record instream flow target and *WR* record diversion and hydropower targets. An annual flow limit from a *FF* record is combined with monthly coefficients from *UC* records to obtain monthly volumes. A monthly target may be further adjusted by *DI/IS/IP*, *SO*, *FS*, and *TO* record options described in the *Users Manual*. The flood index entered in *FF* record field 6 is connected to *IS* and *IP* records and applied identically as the drought index used with *WR* and *IF* records. The monthly target setting routines are essentially identical for *FF*, *IF*, and *WR* record targets. The resulting monthly volume is divided by the number of days in the month to obtain a daily volume.

The forecast period entered in *FF* record field 5 is defined the same as the forecast period entered on a daily water right data *DW* record connected to a water right *WR* record. However, the forecast period and associated forecasted regulated flows supporting flood control operations

are connected to individual *FF* record control points. For *WR* record water rights, the forecast period and associated water availability estimates are defined for water rights.

The daily flood flow volume limit L_{FF} determined by adjustments to the annual volume entered on a *FF* record is used in the simulation computations to determine the remaining flood flow capacity C_{FF} at a control point for a given day defined by Equation 5.1.

$$\begin{aligned} C_{FF} &= L_{FF} - Q_R && \text{if } Q_R \text{ is less than } L_{FF} \\ C_{FF} &= 0 && \text{if } Q_R \text{ is greater than or equal to } L_{FF} \end{aligned} \quad (5.1)$$

where Q_R is the regulated flow at the control point that day, and L_{FF} is the daily flood flow limit set by a *FF*, *UC*, and other optional associated records. Q_R , L_{FF} , or C_{FF} are used in the simulation in conjunction with *FF* record control points to:

- determine whether to store flood waters and if so the volume
- determine whether or not to release water from flood control pools and, if so, the volume of the releases

Each *FR* record reservoir is considered in priority order to determine whether or not to store flood inflows. For each *FF* record control point located downstream of the reservoir, the regulated flow (Q_R) for the current day and each day of the forecast period are compared to the flow limit (L_{FF}). Q_R and L_{FF} are compared for the current day at the control point of the reservoir. Available reservoir inflow is actual inflow less flow that is passed through for downstream senior appropriations. The reservoir stores all available inflow up to either:

- its flood control pool storage capacity or
- the amount that Q_R exceeds L_{FF} in one or more days at one or more control points.

Each reservoir is considered in order as release decisions are made each day. The control point of the reservoir is considered for the current day C_{FF} but not for the C_{FF} for the future days in the forecast period. The controlling flow capacity CC_{FF} is determined as the minimum of:

1. the C_{FF} for the current day at the control point of the reservoir or at any downstream control point identified by *FF* records that are less than 1 day of travel time between the *FR* and *FF* record locations
2. C_{FF} for any day of the forecast period at any of the downstream control point identified by *FF* records.

The adjusted CC_{FF} in Eq. 5.2 reflects adjustments for reverse channel loss in the current and future days, reverse routing in future days, and forward channel loss and routing computations. As each reservoir is considered in a given day in the priority sequence, the CC_{FF} is reduced by the volume of flood releases (R_{FF}) for that day from other reservoirs already considered.

$$\text{Adjusted } CC_{FF} = CC_{FF} - \sum R_{FF} \quad (5.2)$$

The reservoir release (R_{FF}) for that day for the reservoir being considered is then set at the adjusted CC_{FF} . End-of-period reservoir storage is adjusted for the release and also for net evaporation. The release is routed to the basin outlet, thus affecting regulated flows at downstream control points during that day and subsequent days.

Reservoir Operating Rules Defined by *FR* Records

A *FR* record defines operating rules for a flood control reservoir, which may be operated as an individual reservoir or as a component of a multiple-reservoir system. One *FR* record and one *WS* record are required for each flood control reservoir. Any number of *FR/WS* and *WR/WS* records with various auxiliary records may be associated with the same reservoir. The *Users Manual* provides instructions defining the variables in each of the fields of the *FR* record, which are also listed below in Table 5.3. Fields 11 and 12 are typically blank, with defaults adopted.

Table 5.3
Flood Control Reservoir *FR* Record Input Variables

Field	Description
1	Record identifier (<i>FR</i>)
2	Control point identifier of reservoir location
4	Storage priority number
4	Release priority number
5	Number of <i>FF</i> record limits, default = all
6	FCDEP option switch
7	FCMAX Maximum release volume per time interval
<i>Storage Volumes</i>	
8	FCTOP Total storage capacity at top of flood control pool
9	FCGATE Storage capacity at top of controlled flood control pool
10	FCBOTTOM Total storage capacity at bottom of flood control pool
<i>Multiple-Reservoir System Balancing</i>	
11	Multiplier factor M, default = 1.0
12	Addition factor A, default = 0.0
<i>Optional Water Right Identifiers</i>	
13	Water right identifier for storage right
14	Water right identifier for release right

Storage Levels

Storage capacities entered in *FR* record fields 8, 9, and 10 are total cumulative storage volumes below the pool levels shown in Figure 5.3. The capacities are defined as follows.

Field 8: Top of flood control pool (FCTOP) – Upper limit to which flood waters can be stored. If the top of flood control pool is exceeded, outflow equals inflow.

Field 9: Top of controlled flood control pool (FCGATE) – Upper limit to which releases are governed by maximum allowable downstream flow rates specified on *FF* records.

Field 10: Bottom of flood control pool (FCBOTTOM) – Flood releases do not occur from storage below this level, which is normally but not necessarily the top of conservation pool.

A single *WS* record must follow each *FR* record or a group of *FR* records for the same reservoir. The *WS* record is described in Chapter 3 of the *Users Manual*. The beginning-of-simulation storage contents of a flood control reservoir may be entered in field 8 of the *WS* record that follows the *FR* record. With a blank or zero *WS* record field 8, the default is to begin the simulation with the flood control pool empty. Field 8 of the *WS* record that follows a *WR* record sets the beginning-of-simulation conservation pool storage contents.

Priority System for Sequencing of Simulation Computations

A fundamental central concept of a monthly *SIM* or sub-monthly (daily) *SIMD* simulation is that water rights are considered in priority order. The model-user controls the sequence in which computations are performed during a simulation by assigning priority numbers in water right *WR*, instream flow *IF*, and flood control reservoir *FR* records.

Reservoir operating decisions in *SIMD* are made in two stages:

1. closing the gates because a flood has been determined to be in progress or imminent (storage decision)
2. controlling the gates to make releases to empty or draw-down the flood control pool (release decision)

For each day of the simulation, first a decision is made of whether to keep the gates closed. If the answer is "*yes close the gates*," storage capacity is filled by inflows, but releases from the controlled flood control pool are not considered. Otherwise, the controlled flood control pool release decision algorithm is activated. Thus, the storage priority should always be senior to the release priority, meaning the storage decision should precede the release decision in the simulation computations.

Storage and release priorities are entered in *FR* record fields 3 and 4, respectively. The priority numbers are key features for defining operating rules. Priorities control the sequential order in which rights (sets of water control facilities and operating practices) are considered in the computations. The organizing concept of a water rights priority loop nested within a period loop is fundamental to the modeling system. *FR* record rights will normally be assigned priorities that are junior to *WR* and *IF* record rights. Thus, the computations associated with operating flood control reservoirs will be performed last in the water rights computational loop.

As noted above, the release priority (field 4) for a particular reservoir should always be junior to its storage priority (field 3). An error message is activated by *SIMD* otherwise. The field 3 release priority sets the order in which each reservoir is considered in regard to releases from controlled flood control pools. Release priorities are used only with reservoirs for which operators make release decisions, not with uncontrolled flood retarding structures.

For controlled flood control reservoirs, the storage priority in field 3 defines the order in which flood control gates are closed. For uncontrolled reservoirs, the storage priority defines the order in which routing computations are performed. In either case, reservoirs will typically be assigned priorities listing them in upstream-to-downstream order. Gates are often operated to store flood waters as far upstream as possible. Routing through uncontrolled structures also naturally progresses from upstream to downstream.

Options Related to Storing Stream Flow in Flood Control Pools

Four basic tasks performed by *SIM* and *SIMD* as each water right is considered in the priority sequence are described in Table 3.1 of Chapter 3. Task 1 consists of determining the amount of stream flow available to the right based on the control point flow availability array. The switch parameter FCDEP entered in flood control reservoir *FR* record field 6 provides two alternative options for performing task 1 when filling storage in a flood control pool.

1. With FCDEP option 1, the amount of stream flow available to the *FR* record right for filling storage in the flood control pool is based upon current flow amounts in the control point flow availability array at the control point of the water right and all downstream control points.
2. With FCDEP option 2, the amount of stream flow available to the *FR* record right for filling storage in the flood control pool is based upon current flow amounts in the control point flow availability array at the control point of the water right only. Downstream control points are not considered.

Flood control outlet gates are closed, with no releases, whenever flood flow limits are exceeded. In storing flood flows, the default FCDEP option 1 applies the control point flow availability array in the conventional *SIM* manner, designed for water supply operations, in which available flow is the lesser of the flow amount at the control point of the *FR* record reservoir and all downstream control points. Option 2 considers only the control point of the reservoir and the amount of channel capacity exceedance at the downstream *FF* record rights. Flood inflows to the reservoir in a given day may be much higher than the flows at downstream control points due to the flood wave not yet reaching the downstream sites. Option 2 stores reservoir inflows regardless of water availability considerations further downstream. The amount stored with option 2 equals the lesser of the regulated flow at the reservoir control point, the available flood control storage capacity, or the diversion amount required at the reservoir in order to alleviate flooding at downstream *FF* record rights. With option 1 the flow volume available to be stored in the flood pool is constrained by consideration of downstream flows as well as reservoir inflows. Thus, option 2 may result in higher storage levels in flood control pools than option 1. FCDEP option 2 is recommended in most cases.

SIM and *SIMD* monthly simulation computations always maintain volume balances that properly account for all inflows, outflows, and changes in storage. However, due to inaccuracies in forecasting and routing, control point flow availability array values may drop below zero in the *SIMD* computations. Rather than create negative regulated flows, *SIMD* sets regulated flow equal to zero and postpones consideration of the necessary amount of routed depletions until the next time step. The routed depletions are applied to regulated flows at the start of in the next time steps until regulated flow meets or exceeds the amount of routed depletions. Adjustment of the timing of routed depletion consideration allows stream flows to remain at or above zero and also maintains the long-term volume balance. FCDEP option 2 may significantly increase the number and amounts of routing adjustments in subsequent days. Parameter RTGSMM in *JT* record field 13 activates an option in which monthly totals of routing adjustments are tabulated in the message file on a control point basis.

Flood control operations are repeated during both simulations with the dual simulation option activated by *JO* record field 14 or *PX* record field 2. However, second-simulation flood control storage depletions are not limited to first-simulation flood control storage depletions.

Multiple-Reservoir System Operations

All reservoirs having the same priority are treated as components of a multiple-reservoir system in operating controlled flood control pools based on *FF* record allowable flow criteria. Each *FR* record right has a priority for storing flood flows (field 3) and a separate priority (field 4) for the subsequent release of the stored flood waters. If multiple reservoirs share the same storage priority, these reservoirs are treated as a multiple reservoir system in making storage decisions. If multiple reservoirs share the same release priority, these reservoirs are treated as a multiple reservoir system in making release decisions.

Two or more reservoirs with the same priorities (*FR* record field 3 and/or field 4) are treated as a multiple-reservoir system. The rank index computed with Eq. 5.4 sets the order in which the reservoirs are considered in making operating decisions. However, for reservoirs with the same priority, if their computed rank index values are the same in a particular time step, the reservoir with *FR* listed first in the DAT file is selected.

At each time step, the ordering of reservoirs in a multiple-reservoir system for purposes of operating decisions is based on a ranking index. At the beginning of each day of the simulation, a rank index is computed with Equation 5.4 for each reservoir included in the system based on beginning-of-period storage.

$$\text{rank index} = (\text{multiplier factor}) \left[\frac{\text{storage content in FC pool}}{\text{storage capacity of FC pool}} \right] + \text{addition factor} \quad (5.3)$$

Equation 5.3 can be written more concisely as Equation 5.4.

$$\text{rank index} = M \left[\frac{\text{content}}{\text{capacity}} \right] + A \quad (5.4)$$

The flood control pool capacity in Eq. 5.4 is the cumulative storage volume entered in *FR* record field 9 (FCGATE) or field 8 (FCTOP) if field 9 is blank minus the storage volume entered in field 10 (FCBOTTOM). The storage content is the beginning-of-period storage volume less the field 10 storage volume. The defaults are 1.0 for the multiplier factor *M* and 0.0 for the addition factor *A*. *FR* record fields 11 and 12 are used to enter values other than these defaults.

The rank indices computed each day for each multiple-reservoir system reservoir set the order in which operating decisions are made for the individual reservoirs.

- In making storage decisions, the reservoir with the smallest rank index is considered first, the reservoir with the second smallest index is considered second, and so forth.
- In making release decisions, the reservoir with the greatest rank index is considered first, the reservoir with the second largest index is considered second, and so forth.

The selection of the order in which multiple reservoirs store or release flood waters in the simulation priority sequence in each computational time step can significantly affect the storage contents of the individual reservoirs. Multiple-reservoir operating decisions are based on prioritizing reservoirs in the computational sequence as outlined above based on:

1. first considering the priorities assigned in *FR* record fields 3 and 4
2. then applying the rank index (Equation 5.4) if the *FR* record priorities are the same
3. order in which the *FR* records are entered in DAT file if the rank indices are the same

Storage-Area Relationship

A relationship between storage volume and surface area is required for evaporation computations. The storage-area relationship for a reservoir is provided as a table entered on *SV* and *SA* records or as coefficients entered on a *WS* record. Coefficients may be entered in *WS* record field 4, 5, and 6. Blank *WS* fields 4, 5, and 6 indicate that either *SV/SA* records are provided or coefficients were assigned by previous *FR/WS* or *WR/WS* records. If multiple water rights are associated with the same reservoir, the storage-area relationship may be specified with the first right read. Thus, the storage-area relationship may be defined by either previous *FR/WS* pairs or a *WS* record paired with a *WR* record previously read for the reservoir. The maximum number of volume/area points in a *SV/SA* record table is set by *JD* record field 11.

Summary of SIMD Simulation of Reservoir Operations During Floods

Reservoir operations depend upon storage contents relative to the pools shown in Figure 5.3. The parameters entered on *FR*, *FF*, *FV*, and *FQ* records control storage in the flood control pool and releases therefrom. Flood control pool operations are activated only during the days of the simulation in which the storage contents is at or above the bottom of the flood control pool.

The storage volume versus daily outflow (spill or release) volume relationship defined by a *FV/FQ* record table is applied differently for the uncontrolled pool above FCGATE and the controlled pool between FCBOTTOM and FCGATE. When inflows result in storage encroaching into the uncontrolled surcharge pool, outflows are controlled solely by the storage-outflow relationship from the *FV* and *FQ* records. With storage below FCGATE, a *FV/FQ* record storage-outflow relationship provides an upper limit on releases representing the hydraulic release capacity of the outlet structures. A storage-outflow table on *FV* and *FQ* records is applicable to an individual reservoir without consideration of multiple-reservoir systems.

A pair of *FV* and *FQ* records can also be used to model maximum allowable channel capacities in the river reach below a dam that vary as a function of storage contents of the flood control pool. A *FF* record can be combined with a set of *DI*, *IS*, *IP*, and *IM* records to model maximum allowable flow limits at downstream gaging stations that vary as a function of storage contents of the flood control pools of one or multiple reservoirs located upstream.

The following discussion focuses on *FR/FF* record controlled flood control storage. These operations are applicable to either single reservoirs or multiple-reservoir system operations. In each day of the simulation, flows at the *FF* record control points located at or downstream of each flood control reservoir are considered. Flows in the current day at *FR* record reservoirs are also

considered for those reservoirs with maximum release limits specified in *FR* record field 7. If flows at one or more control points in the current or forecast days exceed flood limits, outlet gates are closed at that reservoir for that day. Otherwise, if channel flow capacity is available, releases are made in an amount equal to the minimum flow capacity considering all pertinent control points and all pertinent days. As each reservoir makes releases, the channel flow capacity available to subsequent reservoirs is reduced. In a given day, the entire available channel capacity may be exhausted by the first reservoir considered, or perhaps two or more reservoirs may be able to make releases within available flow capacity. Reverse channel loss and reverse routing are incorporated in the operations decision process.

FR record field 5 provides an option that allows operating decisions to be limited to consideration of only certain *FF* record control points located closest to the reservoir. The number of *FF* record control points to be considered in making operating decisions is entered in *FR* record field 5. For example, a 2 in field 5 means that only the two *FF* record control points at or downstream but closest to the reservoir are considered. With *FR* field 5 blank or zero, the default is for all *FF* record control points located at or below the reservoir to be considered.

A maximum reservoir release rate *FCMAX* may be entered in *FR* record field 7 in dimensions of volume per period (day). This *FCMAX* flow limit is equivalent to the daily flow limit derived from the *FF* record field 3 annual flood flow limit but differs as follows.

- The release limit *FCMAX* is entered directly as a volume/day in *FR* record field 7. Releases at the dam are limited to *FCMAX* less other releases through the dam.
- The flood flow limit starts as a volume/year entered on a *FF* record, with the daily rate then computed based on a *UC* record and optionally further adjusted based on *TO*, *SO*, *FS*, and *DI* records in the same manner as *IF* record instream flow targets.
- The *FR* record maximum release limit applies only to the one reservoir. The *FF* flow limits may be applied to any number of reservoirs in a multi-reservoir system.
- The *FR* record maximum release limit applies only to the current day. Forecasted flows are not considered in applying the limit. Flow for future days during the forecast period are considered in applying the *FF* record flood flow limits.

Switch parameter *WRMETH* in *JU* record field 5 sets whether changes in river flows caused by flood control operations (storage and releases) in preceding time steps are placed within the priority sequence or at the beginning of the priority sequence in each time step. *WRMETH* option 2 adheres to the priority sequence, but option 1 precedes priorities. *WRMETH* option 1 may affect the amount of water available to water rights in the priority sequence as a result of flood control operations. However, option 1 is typically best for flood control operations. Effects of the flood control reservoirs on each other are more accurately modeled with option 1. Flood control deletions and releases are not made during the forecast simulation. Thus, options for *JU* record parameter *WRFCST* are not relevant to flood control routing.

Flood control operations for either a single reservoir or each individual reservoir operated as a component of a multiple-reservoir system include the following decision rules.

- Gates are closed, storing available inflows, if flood conditions are declared based on comparing river flows to *FF* record allowable flood flow limits at control points

located at or downstream of the reservoir and FCMAX. Inflows are stored subject to not exceeding the total storage capacity at the top of flood control pool FCTOP.

- Releases are governed by the *FF* record flow limits, *FR* record outflow limit, and operating rules previously discussed as long as the storage contents is between the limits defined by *FR* record fields 8 and 10. *FR* record flood releases are not made if the storage level falls below the bottom of flood control pool defined in field 10. Outflow equals inflow after the flood control storage capacity is completely filled to the top of flood control pool level defined in *FR* record field 8.
- A *FV/FQ* record storage-outflow relationship controls outflows any time storage is at or above FCGATE. An iterative algorithm determines the outflow volume during the day based on averaging beginning-of-day and end-of-day storage volumes.

Ordering of reservoirs in the simulation computations is based on priorities and relative rank indices. The computational sequencing can significantly affect the allocation of storage contents between reservoirs. Refilling storage and releasing from storage are handled separately in the computations. The sequencing between multiple reservoirs of both aspects of reservoir operations affects the allocation of flood waters stored in the different reservoirs. Computational sequencing is important for multiple reservoirs operated individually as well as multiple-reservoir systems. The sequence in which reservoirs are considered in the simulation computations is based on priorities assigned on the *FR* records. A multiple-reservoir system is defined as two or more reservoirs with either the same storage priorities or the same release priorities. Multiple-reservoir system operating decisions are based on the rank index of Equation 5.4. The rank index may be the same for all of the reservoirs. For example, the storage may be at the top of conservation pool (bottom of flood control pool) in all of the system reservoirs. In this case, the reservoir with *FR* record listed first in the DAT file is considered first in the simulation computations.

CHAPTER 6 ENVIRONMENTAL FLOW STANDARDS

Senate Bill 3 (SB3) environmental flow standards (EFS) are described in Chapter 4 of the *Reference Manual* in a section entitled "*Environmental Flow Standards*". The flow standards are based on a flow regime that includes subsistence, base, within-bank high pulse, and overbank high pulse flows [6, 13, 14]. Hydrologic condition *HC*, environmental standard *ES*, pulse flow *PF*, and pulse flow supplemental options *PO* records are designed specifically to model *IF* record instream flow rights in the format of SB3 environmental flow standards. *HC* and *ES* input records are described in Chapter 3 of the *Users Manual* and Chapter 4 of the *Reference Manual*. *PF* and *PO* input records are covered in Chapter 4 of the *Users Manual* and this Chapter 6 of this *Daily Manual*. An example of modeling SB3 environmental flow standards with *HC*, *ES*, *PF*, and *PO* records is presented in Chapter 8 of this *Daily Manual*.

HC and *ES* records are applicable for either a monthly *SIM/SIMD* simulation or a daily *SIMD* simulation. *PF* and *PO* records are applicable for only a daily *SIMD* simulation. *ES* records describe subsistence, base, and high flow components of environmental flow standards. *PF* and *PO* records model pulse flow components of environmental flow standards. *HC* records define hydrologic conditions for which alternative *ES* and *PF* record quantities are applicable.

The purpose of *HC*, *ES*, *PF*, and *PO* records is to control computation of a minimum instream flow target for each month of a monthly *SIM* or each day of a daily *SIMD* simulation. With these records employed, an *IF* record water right in a monthly *SIM* simulation input dataset consists of an *IF* record followed a *HC* record and a set of *ES* records. A set of *PF* and *PO* records can be added for a daily *SIMD* simulation.

This chapter begins with a summary overview of *SIM/SIMD* options for modeling water rights in general and instream flow requirements in particular. The chapter then outlines methods designed specifically for modeling SB3 environmental flow standards (EFS), focusing particularly on pulse flow components of a flow regime. The last section of Chapter 6 outlines a strategy for developing aggregated monthly instream flow targets computed in a daily *SIMD* simulation for incorporation in an input dataset for a monthly *SIM* water availability model. Examples are presented in Chapter 8 illustrating the modeling methods described in Chapter 6.

WRAP Water Rights

Capabilities for representing water rights in a *SIM* or *SIMD* simulation are explained in Chapter 4 of the *Reference Manual* and Chapter 2 of this *Daily Manual*. Relevant *SIM* and *SIMD* input records are described in Chapters 3 and 4 of the *Users Manual*.

A water right in the WRAP modeling system is defined as a set of water management requirements and capabilities described by a set of records in a *SIM* or *SIMD* input DAT file consisting of either an *IF*, *WR*, or *FR* record and other optional auxiliary records that could include *HC*, *ES*, *PF*, *PO*, *WS*, *TS*, *TO*, *SO*, *FS*, *CV*, *DI*, *IS*, *IP*, *DW*, *DO*, or other types of records. Any number of model water rights may be employed in combination to simulate an actual water right permit or other aspects of water allocation and management. Water management is modeled based on the following three different types of water rights.

- An *IF* record water right specified by an instream flow *IF* record and optional supporting auxiliary input records simulate instream flow requirements (targets).
- A *WR* record water right specified by a water right *WR* record and optional supporting auxiliary input records simulate water supply diversion, hydroelectric energy generation, and/or reservoir storage requirements (targets).
- A *FR* record water right specified by a flood control reservoir *FR* record and optional *FF*, *FV*, and *FQ* records simulate operations of a reservoir for flood control.

Instream flow requirements are modeled in *SIM* and *SIMD* as water rights defined by an *IF* record and auxiliary supporting input records. Many of the same types of optional auxiliary records are applicable with either *IF* or *WR* record rights. *HC*, *ES*, *PF*, and *PO* records are designed specifically for *IF* record water rights, but are generic in that they can also be applied with *WR* records. An instream flow *IF* record water right sets a target minimum regulated flow rate at a control point location for each monthly or daily simulation time step. The objective is to maintain regulated flows equal to or greater than the instream flow targets. Instream flow requirements typically represent environmental flow needs for preservation and enhancement of ecosystems, fisheries, and wildlife habitat but may also serve various other purposes such as recreation, aesthetics, water quality, and water supply.

Instream flow rights may be assigned to any control points. By default, the *IF* record applies only to the one control point specified in *IF* record field 2. Individual control points will each have their own different *IF* records. However, though typically not employed, the optional parameter CP2 in *IF* record field 14 allows the same *IF* record target to be repeated at all control points in a defined reach.

Water allocation routines in *SIM* and *SIMD* are based on user-assigned priorities for all rights, which include instream flow requirements as well as diversion, storage, and hydroelectric energy requirements (demands or targets). Any number of instream flow requirements (*IF* record rights) may be input for a particular control point, with the default option of the next more junior *IF* record target replacing the latest more senior target in the priority-based water rights sequence. As each water right is considered in turn in the priority sequence, 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 or otherwise changed later in the priority sequence.

Normally, a set of all *ES* records, set of all *PF/PO* records, and a *HC* record for a particular control point will be placed behind a single *IF* record in the DAT file. However, components can be split between two or more *IF* records. The option selection parameter IFM(IF,2) on the *IF* record controls selecting between instream flow targets at the same site computed in the priority sequence based simulation as specified by multiple *IF* records located at the same control point. The three options are as follows. (1) The junior *IF* record target replaces the preceding more senior *IF* record target. (2) The largest of the two sequential *IF* record targets is adopted. (3) The smallest of the two targets is adopted.

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

The amount of water available to a right in the *SIM/SIMD* priority computation sequence is based on yet unappropriated flows at the control point of the right and all downstream control points. *IF* record rights add constraints limiting water availability based on regulated stream flow targets. Water supply diversion and reservoir storage rights that are junior to an instream flow right may have the amount of water available to them constrained. The minimum regulated flow target set by an *IF* record right may result in curtailment of stream flow depletions for diversions and reservoir storage refilling at control points located upstream. This curtailment may result in increases in the streamflow available to water rights located further downstream.

Reservoirs located upstream and filled by junior *WR* record rights must pass inflows as necessary to maintain senior downstream *IF* record instream flow targets. Passing inflows during each time step means making releases not exceeding inflows. Releases from storage (releases exceeding inflows) are required from only those reservoirs identified on *WS* records that follow the *IF* record in the DAT file. *IF* record rights may include *WS* records, but typically do not.

Building Targets for Instream Flow Rights

The following alternative *IF* record instream flow target setting procedures may be adopted.

1. *IF* instream flow targets as well as *WR* record diversion or hydropower targets can be established through a step-by-step procedure that begins with the annual target amount entered in *IF* or *WR* record field 3 and progresses through a series of optional computational steps controlled by the records noted below.
2. An entry of -9 in *IF* record field 3 switches to a target setting procedure that employs a *HC* record and set of *ES* records to model the subsistence and base flow components of environmental flow standards. *PF* and *PO* records can be added to model the pulse flow components of the standards. Thus, *IF* record instream flow rights are modeled in the format of SB3 environmental flow standards.

Typically either the first or second strategies listed above, not both, is employed to model a particular instream flow *IF* record right. However, the two strategies can be combined. An initial instream flow target can be first determined with the second strategy employing *HC*, *ES*, *PF*, and/or *PO* records. This initial target is then adjusted following the first strategy listed above employing *TS*, *TO*, *SO*, *FS*, *CV*, *DI*, *IS*, *IP*, *DW*, *DO*, and/or other *SIM/SIMD* input records. *HC*, *PF*, and *PO* records can also be combined with these other records rather than with *ES* records.

The *SIM/SIMD* instream flow target building process may consist simply of uniformly distributing an annual target input in *IF* record field 3 over the months and days of each year. The following discussion addresses more complex target setting options. Regardless of the complexity of multiple-step target building options that may be employed, the result is an instream flow target for a particular month of a *SIM* monthly simulation or target for a particular

day of a *SIMD* daily simulation. An instream flow target is employed in the *SIM/SIMD* simulation to protect stream flow from being appropriated by other junior rights in the same manner regardless of the manner in which the target was established.

A comprehensive flexible array of options are available in *SIM/SIMD* for modeling instream flow requirements as *IF* record water right targets using various combinations of the various techniques provided by *IF* records and auxiliary records. The following records described in Chapter 4 of the *Reference Manual* and Chapter 3 of the *Users Manual* are applicable to either *IF* or *WR* record water rights and to either monthly or daily simulations.

- Use coefficient *UC* record to distribute annual target over the 12 months of the year.
- Drought index *DI*, *IP*, *IS*, *IM* records relating the target to reservoir storage contents.
- Flow switch *FS* record that turns targets on or off depending on specified conditions.
- Cumulative volume *CV* record basing target on accumulation of a specified quantity.
- Targets options *TO* record basing target to conditions defined by specified variables.
- Supplemental options *SO* record for defining various optional features of water rights.
- Target series *TS* record allowing externally developed targets to be input to *SIM/SIMD*.

The *UC* record referenced by an *IF* record is inserted in the DAT file within the set of all *UC* records. Drought indices (*DI*, *IS*, *IP*, *IM* records) are placed at the end of the DAT file. The other records listed above are grouped together following directly behind their *IF* or *WR* record. Flow switch *FS* and cumulative *CV* records provide options for relating targets to one of 12 alternative variables, including a *HI* record hydrologic index in the DSS or HIS input file.

Other records not directly involved in target building are also included in the set of records following an *IF* or *WR* record that create other features of the water right. The storage *WS* record controls refilling and releases from reservoir storage to meet water right requirements. The priority circumvention *PX* record controls dual simulation and other options.

The following additional types of records described in Chapter 4 of the *Users Manual* provide target specifications for a *SIMD* daily simulation. These daily records are used in combination with the monthly/daily records noted above. These optional records are placed in the set of records that follow the *IF* or *WR* record along with the other records discussed above.

- daily water right data *DW* record
- daily supplemental options *DO*
- pulse flow *PF* record
- pulse options *PO* record

DW and *DO* records provide a set of miscellaneous options. Global defaults for some of the *SIMD* simulation options are selected on the *JU* and *JT* records, subject to changes for selected individual water rights by entries on *DW* records. Most of the *DO* record options deal with daily features of the options controlled by the other monthly/daily records listed above. *PF* and *PO* records deal specifically with pulse flows and are discussed later this chapter.

Instream flow *IF* record rights may be very simple, employing few of the available optional target building features. More complex *IF* record rights may combine various options controlled by the different records noted on the preceding discussion. Instream flow targets are

determined step-by-step within *SIM* following the procedure outlined in the section of Chapter 4 of the *Reference Manual* entitled *Setting Diversion, Instream Flow, and Hydropower Targets*. The daily version of the target setting procedure employed in *SIMD* is outlined in Chapter 2 of this *Daily Manual* in the section also entitled *Setting Diversion, Instream Flow, and Hydropower Targets*. The same target-building objectives can be creatively accomplished in different ways.

The preceding paragraphs outline comprehensive, flexible options for modeling instream flow requirements that can be applied and combined in various ways. The remainder of this chapter focuses on a subset of these water right modeling capabilities that are designed specifically for incorporating SB3 environmental flow standards in water availability modeling.

Modeling SB3 Environmental Flow Standards

The *HC*, *ES*, *PF*, and *PO* records are designed to express *IF* record water rights in the format of Senate Bill 3 (SB3) environmental flow standards. Environmental standard *ES* records model subsistence and base flow components of environmental flow standards for either a monthly *SIM* or daily *SIMD* simulation. *ES* records can also model a high flow component in the in a format similar to subsistence and base flow components. However, the high flow component of SB3 flow standards normally consists of high pulse flow requirements, which are modeled in a daily *SIMD* simulation with *PF* and *PO* records. The pulse flow *PF* and pulse options *PO* records are applicable only in a daily simulation, not a monthly simulation.

HC, *ES*, *PF*, and *PO* records provide flexible generic capabilities that can be employed in various combinations with other types of records as noted earlier in this chapter. However, the *HC*, *ES*, *PF*, and *PO* records are designed specifically to model *IF* record instream flow rights in the format of SB3 environmental flow standards. An *IF* record is followed by an optional *HC* record, optional set of *ES* records, and for a daily *SIMD* simulation an optional set of *PF/PO* records. The hydrologic conditions defined by the *HC* record may be applicable to any or all of the *ES* and/or *PF* records.

The priority river systems for which SB3 environmental flow standards (EFS) have been established to date are listed in Tables 4.3 and 4.4 of Chapter 4 of the *Reference Manual*. These existing published flow standards may be modified in the future. Standards for other river reaches and river basins are expected to be established in the future. The SB3 standards were established by the TCEQ based on the recommendations of expert science teams and stakeholder committees. The standards are based on statistical analyses of observed daily flows at USGS stream gaging stations. Future studies to improve existing SB3 environmental flow standards or to create new standards at other locations could be based on statistical analyses of WAM daily naturalized or simulated daily regulated flows as well as daily observed flows.

All of the SB3 EFS established to date include subsistence, base, 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.

The same *HC* and *ES* records are used for both monthly *SIM* and daily *SIMD* simulations. The multiple alternative sequences of 12 monthly minimum flow limit quantities 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, base, and high flow limits each day depends upon daily regulated flows in a daily *SIMD* simulation. Instream flow targets computed by *SIM* or *SIMD* depend on simulated regulated flow in the monthly or daily time step at the particular point in the water rights priority sequence computations as well as the information on *IF*, *HC*, *ES*, and *PF/PO* records. Computed daily regulated flows differ from monthly regulated flows.

A daily simulation more accurately models the *ES* record subsistence and base flow standards due to better representing within-month daily stream flow fluctuations. The characteristics of pulse flows necessitate a daily simulation for modeling the *PF/PO* record components of SB3 environmental flow standards.

Modeling subsistence and based flows with *ES* and *HC* records is explained in *Reference Manual* Chapter 4 and *Users Manual* Chapter 3. Modeling high pulse flows with *PF*, *PO*, and *HC* records is described in *Users Manual* Chapter 4 and the next section of this *Daily Manual*.

As discussed in Chapter 4 of the *Reference Manual*, SB3 environmental flow standards set minimum instream flow limits at a control point based on the following considerations which are modeled in a *SIM* or *SIMD* simulation based on a selected flow variable *ESV*, which by default is the computed regulated flow, and target setting specifications input on sets of *IF*, *HC*, *ES*, *PF*, and *PO* input records.

- *ES* records model subsistence, base, and high flow components of flow standards. Subsistence flow limits control if the regulated flow is below base flow limits. Base flow limits control if the regulated flow is between base flow limits and high flow limits. High flow limits control if the regulated flow is at or above high flow limits.
- *PF* and *PO* records model pulse flow components of a flow standard.
- Any or all components of the flow standards may vary seasonally or monthly.
- Any or all components of the flow standards may vary with hydrologic conditions, which are defined based on preceding stream flow or reservoir storage content, hydrologic index input on *HI* records or other hydrologic time series variables.

Seasonality and hydrologic conditions are defined on a longer-term monthly rather than daily basis. However, within-month daily fluctuations of naturalized and simulated regulated flows are an important aspect of establishing and modeling environmental flow standards.

Environmental flow standards may vary as a function of hydrologic condition and season of the year. Sets of *ES* records and *PF* records contain separate records for the various combinations of seasons and hydrologic conditions. For example, the environmental flow standards at a control point could be defined base on four seasons (Spring, Summer, Fall, and Winter) and three hydrologic conditions (dry, average, and wet). The flow standards would be modeled with a set of 12 *ES* records and a set of 12 *PF* records along with a *HC* record to define the hydrologic conditions.

High Flow Pulse Components of Environmental Flow Standards

Stream flows resulting directly from major rainfall-runoff events typically have great fluctuations in flow rates over short time spans of minutes to several days. Hydroelectric power releases or other reservoir releases may also result in significant short-term fluctuations in downstream flow rates. These fluctuations are not reflected in a monthly time interval *SIM* simulation. Daily computational time steps greatly improve the accuracy of the *SIMD* simulation in modeling hydrograph variability and water management response to rapidly fluctuating flood or pulse flow events. Of course, in reality flow rates may vary significantly even within a day.

High flow pulses are characterized as being short duration events with rapidly changing flow rates and may include over-bank flooding conditions. The rising limb of a typical high flow pulse hydrograph climbs sharply to a peak, after which flows recede back to base flow levels. Pulse events are considered here to have durations measured in days. The *PF* and *PO* records provide parameters used for initiating, tracking, and terminating high flow pulse events. The SB3 process includes consideration of within-bank versus over-bank pulses. *SIMD* deals with daily regulated flow volumes without differentiation between in-bank and over-bank.

Integration of Pulse Flows in the Overall Target Setting Process

Only one minimum instream flow limit (target) is in effect for a particular control point location for a particular time step and priority step in the water rights priority-based simulation. The minimum instream flow limit (target) to be adopted within the simulation computations in each day of a *SIMD* daily simulation or each month of a *SIM* monthly simulation may be based on multiple sets of input records that can be combined in various ways. Possible strategies for incorporating pulse flow targets in a daily *SIMD* simulation include the following.

Strategy 1 is designed specifically for modeling SB3 EFS. An instream flow right is defined by an *IF* record followed in any order by a set of any number of *ES* records, a set of any number of *PF/PO* records, and a *HC* record. For each day of the simulation, a target will be computed based on the specifications provided by the set of *ES* records that reflects subsistence and base flow components of the flow standards. For each day of the simulation, a *PF/PO* record target will be computed next as specified by the *PF*, *PO*, and *HC* records. By default, the larger of the *ES* record target versus pulse flow *PF* record target will be automatically adopted for that day. However, an option selection parameter in *PF* record field 14 provides the following alternative options for combining a *PF* target with a preceding *ES* or *PF* target. The default option 2 is to adopt the largest of two sequentially computed targets. Option 1 is to replace the preceding target. Option 3 is to adopt the smallest target. Option 4 is to add the two targets.

Strategy 2: The target computed by the strategy outlined in the preceding paragraph can then be further adjusted through one or more steps following specifications from *TS*, *TO*, *SO*, *FS*, *CV*, *DI*, *IS*, *IP*, *DW*, *DO*, and/or other records that may also be included in the set of auxiliary records following the *IF* record. These other target-setting records can be combined with *PF*, *PO*, and *HC* records either with or without also using *ES* records.

Strategy 3: Any number of *IF* record water rights can be assigned to the same control point. An *IF* record followed by *PF*, *PO*, and *HC* records may be used to model the high pulse

flow component of an SB3 environmental flow standard. One or more other *IF* records with *ES* and *HC* records and other auxiliary supporting records can be used to model the other components of the environmental flow standard. This strategy provides additional output management flexibility. *SIMD* stores simulation results in its output files for each individual water right. Thus pulse flow targets can be recorded in the OUT and DSS output files separately from subsistence and base flow components.

Any number of *IF* record rights can be assigned to the same control point. No more than one minimum instream flow limit (target) is in effect in a particular daily (or monthly) time step for a control point at any priority stage of the water right priority sequence simulation computations. The option for selecting between targets for multiple *IF* record rights at the same control point is chosen by the entry for IFM(IF,2) on the *IF* record. The options are as follows. The default option 1 is for a junior *IF* record target to replace the preceding more junior target. Option 2 is for the largest target to be adopted. Option 3 is for the smallest target to be adopted.

Pulse Flow PF and Pulse Flow Supplement Options PO Records

Pairs of *PF* and *PO* records are inserted in the group of auxiliary records that follow an *IF* record. The optional supporting *PO* record, if used, follows the *PF* record. An *IF* record water right may have any number of *PF/PO* records. A *PF* record cannot have more than one *PO* record. *PF* and *PO* record parameters are listed in Tables 6.1 and 6.2. The organization and format of each field of the *PF* and *PO* records are explained in Chapter 4 of the *Users Manual*.

Table 6.1
Pulse Flow *PF* Record Input Parameters

Field	Variable	Description
1	Record identifier	PF record identifier.
2	Flow variable PFV	Regulated (default) or naturalized flow used as tracking variable.
3	Hydrologic Condition	Hydrologic condition defined by <i>HC</i> record.
4	Trigger	Daily flow threshold that initiates a pulse event.
5	Volume	Cumulative volume that terminates a pulse event.
6	Duration	Maximum number of days that terminates a pulse event.
7	Frequency	Number of pulse events per tracking period.
8	Tracking Period	Number of previous days to track pulse events.
9	Start of Season	Month to begin season for tracking pulse events. Default is 1.
10	End of Season	Month to end season for counting pulse events. Default is 12.
11	Season Count	Number of seasons for counting pulses. Default is 1.
12	Flow Options	Options for considering regulated flow within priority sequence.
13	Target Limit	Options for limiting the size of the target set by the <i>PF</i> record.
14	Target Selection	Integration of <i>PF</i> record targets with other targets.
15	SMM File Tables	Options for creating tables of computation results in SMM file.
16	Control Point	Control point. Default is <i>IF</i> record control point.
17	PFID	Optional <i>PF</i> record identifier.
18	PFWR	Water right identifier for <i>FS</i> record FSV options 7-11.

Table 6.2
PO Record Input Parameters

Field	Variable	Description
2	Previous Event	Options for initiating new pulse event after a previous event.
3	Delay	Number of days between previous and new pulse events.
4	Larger Events	Larger pulse events block initiation of smaller pulses.
5	Previous Flow	Regulated flow of previous day considered for initiation.
6	Lower Limit	Lower threshold for terminating pulse event.
7	Upper Limit	Upper threshold and rate of change for terminating pulse event.
8	Change	Rate of change used with upper limit for terminating an event.
9	Season Terminate	Termination of pulse events at the end of seasons.
10	Volume Credit	Event volume for smaller pulse events credited to larger events.
11	Excess Events	Options for counting excess pulse events towards frequency.
12	Event Volume	Exclusion of pulse events failing volume criterion from count.
13,14	PFWR2, PFWR3	Identifiers used with optional initiation criteria.
15,16	PFWR4, PFWR5	Identifiers used with optional termination criteria.

Pulse Flow Computations Controlled by PF/PO Records

A defined high flow event is tracked over multiple days, and the flow during each day is used to set minimum regulated flow limits to be imposed by the *IF* record instream flow right. The variable PFV used to track pulse flow events is selected in *PF* record field 2. The default option 1 is the regulated flow at the control point of the environmental flow standard at the priority of the *IF* record water right in the priority sequence simulation computations. PFV option -1 is regulated flow at the control point excluding releases from upstream reservoirs. PFV option 2 is naturalized flow. Any of the FSV options for the flow switch *FS* record also be employed as the *PF* record PFV. However, regulated flow is the PFV option that is relevant for the environmental flow standards that motivate the *PF* record pulse flow modeling capabilities.

Regulated flow computed at the priority of the *IF* record may not necessarily be the same as the regulated flow at the end of the priority sequence for the time step. The difference in regulated flow within the priority sequence versus regulated flow computed at the end of the time step is affected by upstream *WR* records that are junior to the pulse flow target setting right. Steps 10 through 13 of the procedure outlined on the following pages may be repeated to adjust the total event volume at the end of the time step if regulated flow is selected as the PFV pulse flow variable and option 2 is selected in *PF* record field 12.

Setting targets for pulse flow events within the *SIMD* simulation computations is dependent on the regulated flow (or other selected PFV) in the current day and the sequence of regulated flows (or PFV) within a pulse event. The daily regulated flows are evaluated during the simulation to initiate pulse events according to a daily trigger flow and to track cumulative flow event volume compliance. A pulse event is the consecutive days between and including the days in which regulated flows satisfied the initiation and termination criteria. Once the pulse flow event is initiated, daily targets are set based on the simulated regulated flow (or other PFV) and

the *PF/PO* record specifications until the termination criteria are met. The following terms are used in describing the *PF/PO* record computations.

Initiate: Initiate refers to the decision to declare that a pulse event is engaged based on regulated flow exceeding the trigger criterion and satisfaction of optional initiation criteria.

Engaged: A pulse event that has been initiated and is being tracked is said to be engaged. An engaged pulse may set daily pulse flow targets.

Terminate: A pulse event is no longer engaged if either the total event volume or maximum duration or other optional termination criteria is satisfied. The event is terminated.

Daily Pulse Target: Targets are developed during each day of a pulse event. Daily pulse targets are less than or equal to the daily regulated flow during the pulse event as computed at the priority of the *IF* record to which the *PF* record is attached. Daily pulse targets are not used to set a final target for the *PF* record unless the frequency criterion is still unmet.

PF Record Target: Daily pulse targets that are used to establish a daily *IF* record target.

Target Setting Event: Pulse flow events that set a *PF* record target. The number of pulse events that are less than or equal to the frequency parameter during the tracking period are considered to be target setting events.

Excess Pulse Event: Pulse events that do not set *PF* record targets are labeled as being excess. When the number of pulse events exceeds the frequency parameter, the events are tracked but otherwise do not affect the target setting. Excess pulse events are not tracked unless the excess events option is selected on the *PO* record.

Seasonal Tracking: Pulse events are only initiated and considered for meeting the frequency criterion between a starting and ending month. An optional number of the previous seasons may be considered together for meeting the frequency.

Continuous Tracking: Pulse events are initiated and considered for meeting the frequency criterion over the previous number of time steps equal to tracking period window parameter on the *PF* record.

The following computations are controlled the *PF* and *PO* records. If more than one *PF/PO* record pair is assigned to an *IF* record, the computations are repeated as step 19 of the target building process outlined in Chapter 2. The computations for each *PF/PO* record pair are independent of any other *PF/PO* records assigned to the same *IF* record.

1. The month is checked to be within the seasonal cycle if *seasonal tracking* is selected. The computations are performed for every time step if *continuous tracking* is selected.
2. The value of the daily pulse flow variable PFV is computed. The default PFV is to track regulated flow at the control point and at the priority of the *IF* record.
3. A new pulse is initiated if all of the initiation criteria are satisfied. The initiation criteria include items a and b below plus any combination of options c, d, e, and f.
 - a. This *PF* record is not currently tracking a pulse flow event.

- b. The regulated flow is in excess of the trigger criterion.
 - c. The number of pulse flow events during the tracking period has not exceeded the frequency criteria. This criterion is ignored if the excess pulse event option is selected.
 - d. An optionally specified number of days has occurred since the termination of the previous pulse.
 - e. A pulse flow event with a larger trigger criterion is not currently engaged at the same location according to the larger events option.
 - f. Regulated flow for the previous day is less than the trigger criterion.
 - g. Targets are set or not set by other *IF* record rights or *PF* records.
4. A pulse is terminated prior to setting a *PF* record target if the optional *PO* record termination criteria are met. These termination criteria include:
 - a. A target has been set by the water right indicated by PFWR3 (*PO* record field 14).
 - b. Regulated (PFV) flow is less than the lower threshold.
 - c. Regulated (PFV) flow is less than the upper threshold and has decreased since the previous time step by less than the change variable.
 - d. Targets are set or not set by other *IF* record rights or *PF* records.
 5. If the pulse flow event is terminated by the criteria in step 4, and if the pulse event has failed to achieve to the total event volume criterion, the event is eliminated from consideration to satisfy the frequency criterion.
 6. If a pulse event is engaged, the total volume of the event is updated.
 7. If a pulse is engaged, the number of pulse events engaged during the continuous tracking window or seasonal tracking period is updated for comparison with the frequency criterion.
 8. The *daily pulse target* is computed to be equal the lesser of the following:
 - a. Daily regulated flow,
 - b. Remaining volume to satisfy the total event volume criterion,
 - c. Value of trigger criterion if the *PO* record target limit option is selected.
 9. A *PF record target* is set equal to the *daily pulse target* if all the following criteria are met.
 - a. A pulse event is currently engaged.
 - b. The number of pulse events during the continuous tracking window or the seasonal tracking period is less than or equal to the frequency criterion, i.e., the current pulse event is not considered to be an *excess pulse event*.
 - c. A target has not been set in the current time step by the optional water right indicated by PFWR2 entered in *PO* record field 13.
 10. The pulse event is terminated after setting a *PF* record target if the total volume of the pulse event has exceeded the total event volume criterion.

11. If the pulse flow event has been engaged for the maximum duration number of days, the pulse event is terminated. If the event has failed to satisfy the total event volume criterion, the terminated event is eliminated from consideration to satisfy the frequency criterion specified by *PO* record option event volume.
12. The pulse event is terminated if the current day is the last day of a seasonal tracking period. *PO* record season terminate option may allow pulse events to continue past the last day of the season until terminated by other criteria.
13. Optional daily computations are written to the message SMM file if and as specified in *PF* record field 14.
14. If this is the last day of the last month of a seasonal tracking period, the number of excess flow events, if chosen for consideration, are computed and saved for consideration in the next seasonal tracking period. If more than one seasonal tracking period is to be considered for meeting the frequency criterion, all target setting and excess pulse events in the current season are saved for consideration in future seasonal tracking periods as set by *PF* record season count option.

The default PFV employed in this pulse flow target-building procedure is the regulated flow computed at the priority of the *IF* record. Steps 10 through 13 may be repeated to adjust the total event volume at the end of the time step (end of priority sequence) if regulated flow is selected as the pulse flow variable PFV and option 2 is selected in *PF* record field 12.

Selecting *PF/PO* Record Input Parameters

The *PF* and *PO* records are generalized for modeling diverse variations of high flow pulse standards. The required and optional variables on the *PF* and *PO* records can address a wide range of initiation, termination, and target setting aspects of modeling the pulse flow components within a flow regime. Tables 6.1 and 6.2 list and briefly describe the *PF* and *PO* record input parameters. Additional details of the input records are provided in Chapter 4 of the *Users Manual*. Values are assigned to the trigger, volume, duration, and frequency variables and a selection between continuous or discrete seasonal tracking periods is made on the *PF* record. Other variables on the *PF* record are optional or have default values. If a *PO* record is not provided after a *PF* record, all default values of the *PO* record variables are adopted.

Selecting continuous or seasonal tracking periods is dependent on the expected occurrence of the pulse flow component of the flow regime. If the pulse flow component is defined for a specific season or specific months, seasonal tracking should be selected on the *PF* record. If a pulse flow component is not defined for a specific season or specific months, then a continuous tracking period may be appropriate. A pulse flow with a frequency requirement of 1 event per year or 1 event per multiple years might be modeled with a window equal to 364 or more days prior to the current time step. Alternatively, such a pulse flow could be modeled with a 12 month seasonal tracking period with the option to consider a number of previous seasons.

Excess pulse flow events are most likely to be applied with continuous tracking or with seasonal tracking that includes consideration of previous seasons. Seasonal tracking periods that only consider the current seasonal period may not be suited for considering excess flow events.

This may especially be true for seasonal periods defined by only a few months per year. Considering excess flow events represents a type of pulse flow memory that may not have an ecological significance if several months, seasons, or years intervene.

Excess pulse flow events do not set *PF* record targets and therefore will not result in an *IF* record protection of regulated flow. As such, excess flow events may be particularly prone to failing to reach the total event volume criterion set by the *PF* record. Without an *IF* record target, upstream *WR* record rights may continue to deplete stream flow during the excess pulse flow event. It is recommended that the field 13 event volume option on the *PO* record be selected if excess events are considered for satisfying the occurrence frequency criterion. The event volume criterion will exclude excess as well as target setting pulse events from consideration in satisfying the frequency criterion.

An environmental flow standard may identify pulses of different trigger magnitudes, event volumes, frequencies, and seasons at the same location. The *PO* record larger events option default is to block the initiation of pulse events if another *PF* record at the same location and at any position in the priority sequence has engaged a pulse event with a larger magnitude trigger. Smaller pulses may continue to be tracked if they are initiated prior to the larger magnitude pulse initiation. When the larger magnitude pulse has terminated, the smaller magnitude pulses may resume checking regulated flow for possible pulse event initiation. Multiple *PF* records assigned to the same *WR/IF* record right are processed in the order in which the records appear in the DAT file. Sequencing of *PF* records under a single water right should be considered when using the larger events option.

Total event volume of smaller pulses may be credited towards meeting larger pulse events with *PO* record option volume credit. If a smaller pulse is located at the same control point of a larger pulse requirement, and the smaller pulse is still engaged on the day the larger pulse is initiated, the option volume credit allows the smaller pulse volume to date to serve be credited towards meeting the larger pulse total event volume. If more than one smaller pulse is engaged at the same control point, the largest to date event volume is selected for crediting to the larger pulse.

A new pulse event is eligible for initiation in the time step after the previous pulse event has terminated. The *PO* record can be used to set additional pulse event initiation criteria. An initiation option can be used to ensure that the number of days between the previous event initiation and the new event initiation equals the event duration variable on the *PF* record. A pulse event might initiate and achieve its total event volume requirement in the same day. In such a case, the event is terminated on the initiation day after setting a daily pulse target.

The initiation variable on the *PO* record can be used to exclude consideration of the next pulse event until the number of days equal to the event duration has past even if the daily values of regulated flow are above the triggering criterion. Similarly, the delay variable on the *PO* record can be used to require a number of additional days between pulse termination and initiation. Initiation may also be constrained with the option to require the regulated flow of the previous day to be less than the trigger criterion. This option will tend to increase the number of separate flow events required to meet the frequency criterion, rather than allowing a single large event with a long duration to initiate multiple pulses of the same trigger magnitude.

Aggregating Daily Targets to Monthly Targets

The TCEQ WAM System is constructed based on a monthly computational time step. The month is the optimum time interval for the WAM System. However, environmental flows can be modeled much more accurately using a daily interval. In general, all components of environmental flow regimes can be modeled more accurately with a daily than with a monthly model. However, with a monthly time step, the subsistence and base flow components can be modeled more accurately than the high pulse flow components. Approximating high pulse flow requirements in a monthly model is perhaps possible but necessarily very approximate.

A strategy is outlined here in which instream flow targets are computed with the daily *SIMD* simulation model and provided as input to the monthly *SIM* simulation model. The daily targets computed in the daily *SIMD* simulation are summed to monthly target volumes within *SIMD*. The resulting sequences of monthly target volumes from the *SIMD* simulation results are inserted in the monthly *SIM* input dataset as target series *TS* records in a DSS or TSF file.

Final daily targets combining subsistence, base, and pulse flow components will normally be reflected in the adopted monthly totals. However, alternatively, pulse flow targets can be handled separately from subsistence and base flows as two different *IF* record water rights at the same control point if desired. Instream flow targets can be included in the aggregated monthly DSS or OUT file simulation results of a *SIMD* simulation and input DSS or TSF file for a *SIM* monthly simulation as targets for either individual *IF* record rights or as the final targets at control points that may reflect multiple intermediate targets created at the same control point.

The conversion of DSS records from a *SIMD* simulation output DSS file to *TS* records in a *SIM* hydrology DSS input file is accomplished quickly and conveniently with *HEC-DSSVue*. An alternative little less convenient alternative approach can be employed with *HYD*. The WRAP program *HYD* has a feature activated by the output-input *OI* record that reads targets from a *SIMD* output OUT file and creates target series *TS* records for a *SIM* input file.

Instream flow requirements are reflected in two aspects of a simulation.

1. The instream flow targets at each pertinent control point in each time period are computed and adopted as minimum limits on regulated flows. These minimum flow limit targets represent quantities of stream flow not available for further appropriation.
2. The effects of the minimum instream flow limits are reflected in the subsequent computation of streamflow availability for other more junior water rights.

Monthly regulated flows are different than daily regulated flows in regard to reflecting within-month daily flow variability. The strategy of computing monthly instream flow targets with a daily *SIMD* simulation for inclusion in the input dataset for a monthly *SIM* simulation provides better (more accurate) quantities for the monthly target volumes. However, since the monthly aggregated monthly regulated flows limits are constraining junior rights on a monthly basis, shortages in meeting environmental flow targets and effects on other more junior water rights are still subject to the impreciseness of a monthly simulation. Incorporating instream flow targets from a daily simulation in the input to a monthly simulation can greatly improve the accuracy of the monthly simulation but does not completely resolve preciseness issues.

CHAPTER 7 DAILY VERSION OF FUNDAMENTALS MANUAL WAM

Examples in the *Reference* and *Daily Manuals* expand and build upon the example in the *Fundamentals Manual* [5]. The example water availability model (WAM) presented in the *Fundamentals Manual* is used in Chapters 7, 8, and 9 of this *Daily Manual* to illustrate daily modeling capabilities provided by *SIMD* and *TABLES*. The present Chapter 7 focuses on converting the *Fundamentals Manual* WAM from a monthly computational time step to daily and adding flood control reservoir operations. Comparative analyses of the results of daily and monthly simulations are presented in Chapter 7. SB3 environmental instream flow standards are added in Chapter 8. Frequency analyses of daily *SIMD* simulation results are presented in Chapter 9. The examples in Chapters 7, 8, and 9 illustrate the following modeling capabilities.

- A daily model is developed in Chapter 7 by converting the monthly *Fundamentals Manual* example dataset to daily and adding flood control reservoir operations.
- The *Fundamentals Manual* example includes two simple instream flow rights. Chapter 8 focuses on adding much more complex Senate Bill 3 (SB3) environmental instream flow standards (EFS) to the daily model developed in Chapter 7.
- Examples in Chapter 9 are statistical frequency analyses of annual series created from daily simulation results of the Chapters 7 and 8 daily model. One Chapter 9 example develops and analyzes annual series of minimum 7-day naturalized flow volumes. Others deal with annual series of maximum end-of-day reservoir storage.

Input files for the examples presented in all of the WRAP manuals are available along with the WRAP executable programs. The *SIMD* input files for the example presented in Chapter 7 have the filenames DailyCh7.DAT, DailyCh7.DIF, and ExamplesHYD.DSS. Daily simulation results in Chapters 7, 8, and 9 are from the May 2019 *SIMD* and are identical to results presented in the May 2019 version of the *Daily Manual*. Results derived from the July 2022 *SIMD* are a little different due to modifications described in the *Additions and Revisions Report* [21].

Example in the Fundamentals Manual

The *Fundamentals Manual* is organized around an example of a monthly *SIM* simulation of the system shown schematically in Figure 7.1. The model includes eleven control points, six reservoirs, two instream flow *IF* record rights, and 28 *WR* record water rights including one hydropower right. The hydrologic period-of-analysis is 1940-2017. Simulation results are analyzed using *TABLES* and *HEC-DSSVue*. Detailed descriptions of the river/reservoir/use system along with input files and simulation results are presented in the *Fundamentals Manual*.

The example water availability model (WAM) presented in the *Fundamentals Manual* was adapted from the TCEQ WAM dataset for the Brazos River Basin and Brazos-San Jacinto Coastal Basin, called the Brazos WAM, which has about 700 reservoirs and over 3,000 control points. A daily version of the complete Brazos WAM [7] has been created as noted in Chapter 1. The *Fundamentals Manual* example has six reservoirs and 11 primary control points from the Brazos WAM. The water rights in the example are hypothetical but designed to be reasonably realistic for demonstrating the modeling system. The monthly and daily hydrology input data for

the examples are taken directly from the monthly and daily Brazos WAMs [7]. Storage capacities and surface areas of the six reservoirs are also actual Brazos WAM quantities.

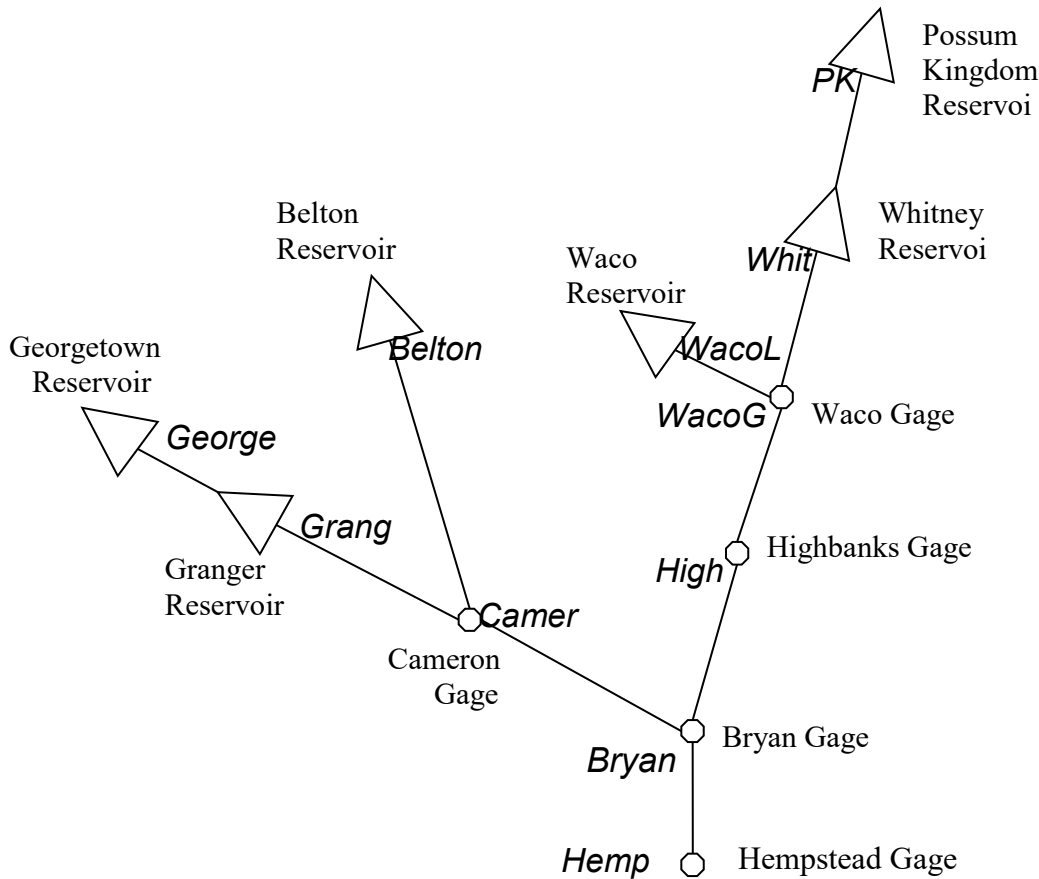


Figure 7.1 System Schematic for the Example

The hydrologic period-of-analysis for the *Fundamentals Manual* example and adaptations thereof presented in this *Daily Manual* is January 1940 through December 2017. The Brazos WAM has 77 primary control points with naturalized monthly flows provided as *IN* records in the input dataset. Flows are distributed within the simulation to over 3,000 secondary control points. The Brazos WAM input dataset has 67 sets of *EV* record 1940-2017 net evaporation-precipitation depths used in the simulation to compute evaporation-precipitation volumes at about 700 reservoirs. The example adopts Brazos WAM 1940-2017 monthly naturalized flows at 11 primary control points, with no secondary control points, and evaporation-precipitation depths for six reservoirs. The example adopts actual storage capacity data for the six reservoirs. The six dams are placed in the model at gage sites listed in Table 7.1 though actually located distances away. The other water rights data are fabricated, reflecting realistic quantities but not directly representing any particular actual water right permits.

The monthly naturalized flows in the example WAM represent observed flows at the U.S. Geological Survey (USGS) gages listed in Table 7.1 adjusted to reflect natural conditions without human water development and use. Daily flows added for the daily version of the WAM input dataset at eight control points (Hemp, Bryan, High, WacoG, Whit, Camer, Grang, and Belton) are used as pattern hydrographs at the eleven control points as described in this chapter.

Table 7.1
Naturalized Flow Sites Adopted for the Example

USGS Gage Identifier	Location by Stream and Nearest Town	Watershed Area (square miles)	TCEQ WAM Control Point	Example Control Point
08088600	Brazos River near Graford	14,030	SHGR26	PK
08093100	Brazos River near Aquilla	17,750	BRAQ33	Whit
08095600	Bosque River near Waco	1,660	BOWA40	WacoL
08096500	Brazos River near Waco	20,060	BRWA41	WacoG
08098290	Brazos River near Highbank	20,900	BRHB42	High
08102500	Leon River near Belton	3,580	LEBE49	Belton
08104700	NF San Gabriel, Georgetown	248	NGGE54	George
08105700	San Gabriel River, Laneport	737	GALA57	Grang
08106500	Little River at Cameron	7,100	LRCA58	Camer
08109000	Brazos River near Bryan	30,020	BRBR59	Bryan
08111500	Brazos River near Hempstead	34,370	BRHE68	Hemp

The monthly *SIM* simulation input dataset for the *Fundamentals Manual* example consists of the DAT and DSS files presented in the *Fundamentals Manual*. The *SIM* hydrology input data consists of *IN* records for the 1940-2017 naturalized flows at the 11 control points and *EV* records with reservoir evaporation-precipitation depths at six control points stored in a DSS file with filename FundExamHYD.DSS. All other *SIM* input data are stored in a DAT file with filename FundExam.DAT. The DAT file includes input records for two *IF* record rights and input record sets for 28 *WR* record water rights which include *WS* records defining the six reservoirs and a *HP* record for the one *WR* record water right with hydropower.

The DAT file is modified as needed, daily flow pattern hydrographs are added to the DSS file, and a DIF file is created as described in this chapter to create a daily *SIMD* input dataset. A *SIMD* daily model allows inclusion of flood control operations (Chapter 5) and tracking of environmental pulse flows (Chapter 6). Flood control reservoir operations are added to the dataset in Chapter 7. SB3 environmental flow standards are added in Chapter 8. Simulation results are analyzed using *TABLES* and *HEC-DSSVue*. Comparative analyses are performed for simulation results for alternative variations of the *SIM* and *SIMD* input datasets.

SIMD Input Records for a Daily Simulation

All *SIM* input records for a monthly computational time step simulation are also relevant in a daily simulation. The following discussion focuses on additional input records employed to convert a monthly *SIM* dataset to a daily *SIMD* input dataset. The types of additional *SIMD* input records used in a daily simulation are listed in Table 7.2. Each input data field of these records is explained in Chapter 4 of the *Users Manual*. The input records are stored in DAT, DIF, and DSS files. The *JT* record is the only additional required record that must be added to a *SIM* input dataset to activate a *SIMD* daily simulation. The other records listed in Table 7.2 are optional. Many but not all of the input record types are employed in the example.

Table 7.2
SIMD Input Records for Daily Simulations
 (Described in Chapter 4 of *Users Manual*)

<u>DAT File</u>	
<i>JT, JU</i>	Simulation job control options.
<i>DW, DO, PF, PO</i>	Daily water right data.
<i>FR, FF, FV, FQ</i>	Reservoir operations for flood control.
<u>DIF File</u>	
<i>DW/SC, DO/SC</i>	Optional placement of <i>DW</i> and <i>DO</i> records.
<i>RT, DC</i>	Routing and disaggregation parameters.
<u>DSS File</u>	
<i>DF</i>	Daily flows.

Shared *SIM* and *SIMD* input records applicable in both monthly *SIM* and daily *SIMD* simulations are explained in Chapter 3 of the *Users Manual*. Input records used only in a daily *SIMD* simulation are covered in Chapter 4 of the *Users Manual*. The file options *OF* record is described in Chapter 3 of the *Users Manual* though entry DSS(3) has options that are relevant only to a daily simulation. The *JD* record explained in Chapter 3 of the *Users Manual* contains input parameters shared by *SIM* and *SIMD*, but some of the input parameters include certain options that are applicable only to *SIMD*.

The *SIM* and *SIMD* daily and monthly time series simulation results recorded in OUT, SUB, CRM, and DSS output files are control by *JD, CO, RO, WO, GO, and OF* DAT file input records the same in both *SIM* and *SIMD* simulations as described in *Users Manual* Chapter 3. Other auxiliary simulation output files relevant only in a *SIMD* daily simulation are controlled by parameters on the *JT* record. A variety of *SIMD* daily simulation options are selected by entries on the *JU* record.

DW and *DO* records control various options for modeling water rights including daily target distribution and target setting options and forecast periods. Defaults set on the *JU* record apply to all water rights unless replaced by *DW* records for individual rights. Forecast periods are automatically determined within *SIMD* unless superseded by parameters entered on *JU* and *DW* records. *SC* records allow *DW* record parameters to be assigned to groups of water rights satisfying specified criteria. *DW, DO, and SC* records are not used in the example in this chapter. The default uniform distribution of monthly diversion and instream flow targets over all the days of each month is applied for all water rights. The number of days in February is 29 in leap years and 28 otherwise and either 30 or 31 for the eleven other months. The simulation forecast period is automatically determined within *SIMD* and applied to each water right.

The *FR, FF, FV, and FQ* records apply to reservoir operations for flood control which are covered in Chapter 5. The example includes flood control operations for six reservoirs.

The parameters provided on *RT* and *DC* records in a DIF file along with *JU* record entries are used by *SIMD* to disaggregate monthly naturalized flow volumes to daily volumes using the options listed in Table 3.2 and to route flow changes through stream reaches using either the lag and attenuation method or *SIMD* adaptation of the Muskingum method. The lag and attenuation routing method is the recommended standard and is employed in the example.

A *SIM* monthly simulation can be performed with an input dataset containing the DAT file records listed in Table 7.2. *SIM* skips over records that are relevant only in a daily simulation. *SIMD* can perform only a daily simulation with a DAT file with one or more of the daily records in Table 7.2 but can perform a monthly simulation without these daily records.

Daily *SIMD* Simulation Input Dataset

All of the *SIM* input files and input records from the *Fundamentals Manual* example continue to be used in the daily *SIMD* input dataset. Records are added to the DAT and DSS files and a DIF file is created to convert the monthly WAM to a daily WAM. The *SIMD* input dataset for the daily WAM of Chapter 7 consists of three files with the following filenames that contain the records shown in parenthesis.

DailyCh7.DAT (all other records)
DailyCh7.DIF (*DC* and *RT* records)
ExamplesHYD.DSS (*IN*, *EV*, and *DF* records)

The DAT and DIF files are reproduced as Tables 7.3 and 7.4. The additional records inserted in the DAT file in the conversion from monthly to daily are shown in boldface in Table 7.3. The hydrology input DSS file is shared by all of the simulations in Chapters 7 and 8. *IN* and *EV* records stored in the DSS file are inherited from the *Fundamentals Manual* example. Daily flows are added to the DSS file as *DF* records as discussed in Chapter 7. Hydrologic index *HI* and target series *TS* records are added to the DSS input file in Chapter 8 along with adding SB3 environmental flow standards in the DAT file.

Input Data in the DAT File

The original monthly *SIM* DAT file is reproduced in Appendix A of the *Fundamentals Manual*. The daily version of the DAT file is reproduced here as Table 7.3 with the new added records and modified fields of the original records shown in boldface. *JT*, *JU*, *DF*, *FV*, *FQ*, *FF*, and *FR* (with *WS*) records are added. Added and modified records are as follows.

- ADJINC option 6 or 7 is selected in *JD* record field 8. TL of 20 is entered in *JD* field 11.
- DSS(3) option 2 is selected in *OF* record field 4 to record simulation results in a DSS file.
- The *JT* record is required for a daily simulation, and the *JU* record activates certain options.
- *DF* record control point identifiers refer to *DF* record daily flows in the DSS input file.
- The *SV/SA* record storage volume versus surface area tables are extended to include flood control pools in the six reservoirs. The *PV/PE* storage volume versus water surface elevation table is extended to include the flood control pool in Whitney Reservoir.
- *FR*, *FF*, *FV*, and *FQ* records are added to model flood control reservoir operations.

Table 7.3
SIMD Input DAT File

```

** File DailyCh7.DAT
** SIMD Input File for the Example in Daily Manual Chapter 7
**      1      2      3      4      5      6      7      8
**34567890123456789012345678901234567890123456789012345678901234567890
**-----!-----!-----!-----!-----!-----!-----!-----!-----!
**
JD   78      1940      1      0      0      7      20
JO   6
OF   1      0      2
JT  0      0      0      0      0      2      2      2      2      1
JU  0      0      0      2      2
DF      Whit      WacoG      High      Belton      Grang      Camer      Bryan      Hemp
**
UC IND1  0.054  0.060  0.070  0.083  0.094  0.105  0.113  0.106  0.096  0.083  0.072  0.062
UC IND2  0.058  0.077  0.087  0.097  0.107  0.124  0.128  0.124  0.078  0.041  0.038  0.041
UC IRR2  0.005  0.008  0.018  0.032  0.075  0.189  0.304  0.253  0.079  0.022  0.008  0.007
UC MUN1  0.065  0.063  0.068  0.072  0.085  0.093  0.118  0.114  0.095  0.087  0.071  0.069
UC MUN2  0.065  0.063  0.066  0.069  0.082  0.105  0.111  0.106  0.100  0.089  0.074  0.069
UC POWER 2250.  2250.  2250.  2250.  2250.  3000.  6000.  6000.  3000.  2250.  2250.  2250.
**
CP   PK      Whit
CP   Whit    WacoG
CP   WacoL   WacoG
CP   WacoG   High
CP   High    Bryan
CPBelton    Camer
CPGeorge    Grang
CP   Grang   Camer
CP   Camer   Bryan
CP   Bryan   Hemp
CP   Hemp
**
** Instream Flow Requirements at Cameron and Hempstead Gages
**
IF Camer  3600.  NDAYS      0      IF-1
IF Hemp  120000. NDAYS      0      IF-2
**
** Possum Kingdom Lake at Control Point PK
**
WR   PK  9800.  MUN1  193804      2      0.35      WR-1      PK
WS   PK  570240.
WR   PK  245000.  IND1  193804      WR-2      PK
WS   PK  570240.
**
** Whitney Lake at CP Whit
**
WR   Whit  18000.  MUN1  198208      2      0.40      WR-3      Whitney
WS   Whit  627100.  379000.
WR   Whit  36000.  POWER  888888      6      2      WR-4      Whit HP
WS   Whit  627100.  379000.
HP   0.86      440.
WR   Whit      888889      WR-5      Refill
WS   Whit  627100.  379000.
**
** Waco Lake at CP WacoL
**
WR   WacoL  60000.  MUN1  192901      2      0.35      WR-6      WacoLake
WS   WacoL  104100.
WR   WacoL  20800.  MUN1  198609      2      0.40      WR-7      WacoLake
WS   WacoL  192100.

```

Table 7.3 Continued
SIMD Input DAT File

```

**
** Belton Lake at CP Belton
**
WRBelton 82760.    MUN1 196312    2    0.45    WR-8    Belton
WSBelton 457600.
WRBelton 97500.    IND1 196312    2    0.20    WR-9    Belton
WSBelton 457600.
**
** Georgetown Lake at CP George
**
WRGeorge 25610.    MUN2 196802    0    0.48    WR-10   George
WSGeorge 37100.
**
** Granger Lake at CP Grang
**
WR Grang 42000.    MUN2 196802    0    0.40    WR-11   Granger
WS Grang 65500.
**
** Cameron Gage - Run-of-River Diversion Rights
**
WR Camer 92100.    IRR2 198211    2    0.35    WR-12   Cameron
WR Camer 18200.    IND2 196105    2    0.50    WR-13   Cameron
WR Camer 11300.    IRR2 194510    2    0.10    WR-14   Cameron
**
** Cameron Gage - Multiple-Reservoir System Diversion Right
**
WR Camer 88000.    MUN2 200601    2    2    0.35    WR-15   SystemC
WSBelton 457600.
WSGeorge 37100.
WS Grang 65500.
**
** Waco Gage - Run-of-River Diversion Right
**
WR WacoG 32300.    IRR2 194607    WR-16   WacoGage
**
** Highbank Gage - Run-of-River Diversion Right
**
WR High 44800.    IRR2 195903    WR-17   Highbank
**
** Bryan Gage - Run-of-River Diversion Rights
**
WR Bryan 25400.    MUN2 198211    2    0.40    WR-18   Bryan
WR Bryan 39000.    IND2 196105    2    0.65    WR-19   Bryan
WR Bryan 34500.    IRR2 194510    2    0.05    WR-20   Bryan
**
** Hempstead Gage - Run-of-River Diversion Rights
**
WR Hemp 49600.    IRR2 194510    WR-22   Hemp
WR Hemp 95600.    IND2 196105    WR-21   Hemp
WR Hemp 74500.    IRR2 200601    WR-23   Hemp
**
** 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.
**

```

Table 7.3 Continued
SIMD Input DAT File

```

** Refilling Storage in Multiple-Reservoir System Reservoirs
**
WR   PK                888888                WR-25          Refill
WS   PK 570240.
WRBelton                888888                WR-26          Refill
WSBelton 457600.
WRGeorge                888888                WR-27          Refill
WSGeorge  37100.
WR Grang                888888                WR-28          Refill
WS Grang  65500.
**
** Flood Flow Limits
**
FF WacoG  50000.
FF Bryan  60000.
FF Hemp   60000.
FF Camer  10000.
**
** Flood Control Reservoirs
**
FR   PK 910000 920000 0 2                665540 570240. 570240.
WS   PK
FR Whit  910000 930000 0 2 25000. 2000000                627100.
WS Whit
FR WacoL 910000 930000 0 2 20000. 726400                192100.
WS WacoL
FRBelton 910000 930000 0 2 10000. 1091320                457600.
WSBelton
FRGeorge 910000 930000 0 2 4000. 130800                37100.
WSGeorge
FR Grang  910000 930000 0 2 10000. 244200                65500.
WS Grang
**
FV   EK 570240. 588230. 606770. 625850. 645450. 665540.
FQ   EK    0. 10083. 22183. 34787.5 50417. 75625.
**
** Reservoir Storage Volume (acre-feet) versus Surface Area (acres) Tables
**
SBelton 0. 40. 160. 650. 1100. 1800. 20900. 58700. 123500. 218100. 304170. 457600. 470000. 535400. 606400. 688800. 788600. 861400. 1074200 1195600
SA      0. 17. 32. 63. 110. 200. 1760. 3270. 5290. 7580. 9261. 12258. 12500. 13680. 14800. 16170. 17700. 19470. 23280. 25380.
**
SGeorge 0. 3. 97. 280. 640. 1250. 2610. 4170. 6310. 11500. 22900. 37100. 42570. 51990. 81600. 112500. 130800. 137370.
SA      0. 2. 19. 45. 77. 130. 237. 323. 410. 620. 958. 1310. 1483. 1667. 2291. 2859. 3241. 3329.
**
SGrang  0. 76. 272. 960. 2200. 3460. 5310. 7030. 10310. 23950. 46600. 65500. 69960. 79500. 95670. 127500. 166300. 212600. 244200.
SA      0. 16. 52. 180. 344. 500. 750. 980. 1230. 1828. 3280. 4400. 4520. 5020. 5789. 7020. 8473. 10050. 11040.
**
SV   EK 0. 236. 865. 3579. 10447. 22038. 25810. 147410. 298092. 504100. 547414. 570240. 588230. 606700. 625850. 645450. 665540.
SA      0. 60. 216. 525. 962. 1403. 1500. 5675. 9875. 14440. 15803. 17700. 18270. 18820. 19940. 19850. 20340.
**
SV WacoL 0. 8. 36. 1438. 3509. 4804. 17091. 29704. 105675. 152500. 207106. 304510. 401742. 517448. 651274. 726360. 828325.
SA      0. 4. 12. 160. 338. 562. 2741. 3524. 5986. 7270. 8465. 11049. 13357. 15517. 18099. 19808. 21388.
**
SV Whit  0. 9. 1145. 4843. 51240. 157245. 379108. 427400. 559219. 627100. 807330. 1120975 1500357 1950148 1999500 2100400
SA      0. 22. 237. 507. 3210. 7500. 15760. 16450. 21740. 23560. 28070. 34920. 41040. 48960. 49820. 51190.
**
** Reservoir Storage Volume (acre-feet) versus Elevation (feet) Table for Hydropower at Lake Whitney
**
FV Whit 2630. 19600. 41710. 79990. 143200. 229400. 363600. 473100. 601800. 782000. 1095000 1473000 1970200 2071100
FE      448.8 470.0 480.0 490.0 500.0 510.0 520.0 527.0 533.0 540.0 550.0 560.0 571.0 573.0
ED

```

Flood control operations activated by *FF* and *FR* records require that the tables of volume-area (*SV/SA* records) and volume-elevation (*PV/PE* records) include the flood control pools of the reservoirs. The default limit is 12 for the number of quantities read from *SV*, *SA*, *PV*, and *PE* records. The TL of 20 on the *JD* record raises this limit from 12 to 20.

The recommended standard *JO* record *ADJINC* negative incremental flow options are option 4 or 6 for monthly and option 7 for daily simulations with forecasting as explained in Chapter 3. Options 4 and 6 are designed to always yield the same results. Option 7 is designed for daily *SIMD* simulations. *ADJINC* in *JO* record field 8 is changed from option 6 to option 7.

OF record DSS(3) option 2 specifies that both daily and monthly totals of the daily simulation results are recorded in the DSS output file. The blank DSS(4) field results in a default set of simulation variables being output to the DSS file. Any set of simulation results variables can be selected with the *OF* record for inclusion in the DSS file. DSS(1) option 1 in *OF* record field 2 means that the monthly totals of the daily results are also recorded in the OUT file. Creation of a SUB output file is controlled by *JT* record field 13, with a default of no SUB file.

The filename root "Examples" of the DSS input file excluding the appended "HYD" is entered in field 13 of (columns 61-92) the *OF* record. With *OF* record field 12 blank, the default is the root of the hydrology input files, which defaults to the root of the DAT file. The *OF* record field 13 file naming option provides added convenience allowing the same DSS hydrology input file to be employed for all of the examples in Chapters 7 and 8 while changing filenames of the DAT and output files for multiple simulations performed for each of the multiple examples.

The *JT* record is required to activate a daily simulation. Non-blank (non-zero) entries in the *JT* record in Table 7.3 control simulation output options. Inclusion of simulation results in the output files for all control points and water rights is specified by the options 1 and 2 in fields 5 and 6 of the preceding *JD* record. The entries on the *JT* record specify creation of flow disaggregation, routing array, water right summary, and routing adjustments tables in the message SMM file.

The *JU* record controls disaggregation and forecasting options. Flow disaggregation option 4 based on daily flow pattern hydrographs is the default for the *JU* record global default DFMETH which is subject to change by DIF file *DC* record DFMETHOD(cp) for individual control points. Option 4 is applied for all eleven control points in the example. The default DFFILE option 1 in *JU* record field 3 means that the *DF* record daily flow pattern hydrographs are read from the DSS hydrology input file. The control points for which *DF* records of daily flows are read from the DSS file are listed on a *DF* record following the *JU* record in the DAT file. Stream flow disaggregation and routing are discussed further later in this chapter.

Forecasting is activated by the entry of 2 for FCST in *JU* record field 6. Since *JU* record fields 7 and 8 are blank, *SIMD* automatically sets the forecast period FPRD and availability forecast period APRD as explained in Chapter 3.

WRMETH option 1 and WRFCST option 2 are selected by entries of 0 (default option 1) and 2 in *JU* record fields 4 and 5. WRMETH and WRFCST options for placement of routed flow changes in the water rights priority sequence in future days are explained on pages 40-42 of Chapter 3 this manual and with the *JU* record description in Chapter 4 of the *Users Manual*.

Input Data in the DIF File

The daily input file, with filename extension DIF, for the example is reproduced as Table 7.4. The DIF file consists of ten *RT* records and a *DC* record along with **** and *ED* records. Although not applicable to this example, a DIF file may also contain *DF* and *DH* records and daily water right information on *DW*, *DO*, *SC*, *DE*, *DH*, and *DF* records. As discussed later, daily flow *DF* records are stored in the DSS file rather than the DIF file in the example dataset. The DIF file is relevant only to a daily, not a monthly, *SIMD* simulation.

Table 7.4
SIMD Input DIF File

```

**  SIMD Input File DailyCh7.DIF
**  Example in Daily Manual Chapter 7
**      1          2          3          4
**345678901234567890123456789012345678901234
**      !      !      !      !      !      !      !      !      !      !
RT      PK      1      6.04      1.0      5.59      1.0
RT      Whit    1      1.00      1.0      1.01      1.0
RT      WacoL   1      0.26      1.0      0.26      1.0
RT      WacoG   1      1.07      1.0      1.00      1.0
RT      High    1      1.81      1.0      1.00      1.0
RTBelton      1      2.00      1.0      2.16      1.0
RTGeorge      1      1.19      1.0      1.00      1.0
RT      Grang   1      1.96      1.0      1.16      1.0
RT      Camer   1      1.21      1.0      1.25      1.0
RT      Bryan   1      1.98      1.0      1.00      1.0
DC      WacoL   4      Belton
ED

```

Routing Parameters

The lag and attenuation method described in Chapter 3 was designed specifically for routing daily flow changes in the *SIMD* simulation and is the recommended routing option for most (perhaps all) applications of *SIMD*. Lag and attenuation routing is activated as *RTYPE*(cp) option 1 in *RT* record field 3. The routing parameters lag and attenuation are provided on the *RT* records in units of days. Separate parameters are provided for normal flows and high flows. The parameters are for the river reach below the control point identified in *RT* record field 2.

The *RT* records in Table 7.4 provide routing parameters for the control points defining the upstream end of the ten river reaches shown in Figure 7.1. Control point Hemp is the basin outlet and thus has no downstream routing reach. As discussed in Chapter 3, in general, routing parameters are not necessarily required for all control points. For example, the daily Brazos WAM [7] with over 3,000 control points includes routing parameters at 58 control points.

Streamflow depletions for diversions and refilling reservoir storage, reservoir releases, and return flows result in stream flow changes that propagate through river reaches to downstream control points. The routing computations consist of lag and attenuation adjustments to the flow changes. The computations are performed at the control points specified on the *RT* records but conceptually represent changes occurring gradually along river reaches.

The calibrated values of the routing parameters lag (LAG and LAGF) and attenuation (ATT and ATTF) for normal (*WR* record) water right operations and flood control (*FR* record) operations are also tabulated in Table 7.5. Travel times corresponding to the lags are tabulated in Table 7.6 for general information.

Table 7.5
Lag and Attenuation Routing Parameters

Upstream CP	Downstream CP	Length (miles)	Normal Flow		Flood Flow	
			LAG (days)	ATT (days)	LAGF (days)	ATTF (days)
PK	Whit	248	6.04	1.0	5.59	1.0
Whit	WacoG	35	1.00	1.0	1.01	1.0
WacoG	High	57	1.07	1.0	1.00	1.0
High	Bryan	67	1.81	1.0	1.00	1.0
Bryan	Hemp	86	1.98	1.0	1.00	1.0
WacoL	WacoG	9	0.26	1.0	0.26	1.0
George	Grang	37	1.19	1.0	1.00	1.0
Grang	Camer	38	1.96	1.0	1.16	1.0
Camer	Bryan	66	1.21	1.0	1.25	1.0
Belton	Camer	81	2.0	1.0	2.16	1.0

Table 7.6
Travel Speeds for Routing Reaches

Upstream CP	Downstream CP	Normal Flow	High Flow	Normal Flow	High Flow
		(miles/day)	(miles/day)	(feet/second)	(feet/second)
PK	Whit	41.1	44.4	2.51	2.71
Whit	WacoG	35.0	34.7	2.14	2.12
WacoG	High	53.3	57.0	3.26	3.48
High	Bryan	37.0	67.0	2.26	4.09
Bryan	Hemp	43.4	86.0	2.65	5.25
WacoL	WacoG	34.6	34.6	2.12	2.12
George	Grang	31.1	37.0	1.90	2.26
Grang	Camer	19.4	32.8	1.18	2.00
Camer	Bryan	54.5	52.8	3.33	3.23
Belton	Camer	40.5	37.5	2.47	2.29

The routing parameter (LAG, ATT, LAGF, and ATTF) values adopted for the example WAM are based on calibrated values of the parameters incorporated in the daily Brazos WAM [7]. Calibration studies performed in the initial development of the original daily Brazos WAM

[6] employed the optimization-based calibration procedure explained on pages 80-87 of Chapter 4 and illustrated with the example on pages 89-94. A new set of routing parameter values for the daily Brazos WAM [7] was recently developed based on applying the new statistical-based procedure described on pages 73-80 of Chapter 4.

The routing parameters in Tables 7.5 and 7.6 are from calibration studies [15] performed for 72 reaches of the Brazos River and its tributaries in conjunction with updating and refining the daily Brazos WAM. The calibration study resulted in a ATT and ATTF values of 1.0 day for most, though not all, of the 72 reaches. ATT and ATTF by definition cannot be less than 1.0 day and in general is expected to be 1.0 for many river reaches.

Parameter calibration studies for the Brazos WAM [11, 15] and other daily WAMs as well as other studies of travel time support the conclusion that travel times and associated lag and attenuation are highly variable and estimates of lag are very approximate and uncertain. Travel times are generally expected to increase with increasing within-bank flows in a river reach but may decrease as rising flows overflow into flood plains with lower flow velocities. Lag times for actual flow changes in observed daily flows have been found to exhibit great variability [11, 15].

The referenced Brazos lag and attenuation studies [15] are based on observed daily flows at USGS gages. All of the 72 reaches investigated are reaches between USGS gaging stations. Eleven of the gaging stations are listed in Table 7.1. Some of the reaches in the example daily WAM corresponding to reaches in the Brazos WAM. For the other reaches, the LAG and LAGF adopted for the example are the summation of the lags for multiple Brazos WAM reaches that comprise a single reach in the example WAM.

Table 7.5 includes estimates of reach lengths for the ten river reaches. The travel speeds in Table 7.6 are computed simply by dividing reach length by lag time and applying unit conversions. Travel times provide insight on river flow characteristics and whether estimates of lag appear to be reasonably valid.

Disaggregation of Monthly Naturalized Flow Volumes to Daily Volumes

Options for disaggregating monthly naturalized flows to daily quantities are outlined in Table 2.2 and explained in Chapter 2. The 1940-2017 monthly naturalized flow volumes at the eleven control points in the example are distributed to daily volumes using option 4 based on 1940-2017 daily flow pattern hydrographs at eight control points provided as input on *DF* records in the DSS hydrology input file. With flow disaggregation option 4, monthly volumes are sub-divided to daily volumes in proportion to daily pattern flow hydrographs while maintaining the monthly totals of the daily volumes. Although different options can be applied at different control points, option 4 is applied to all 11 control points in the example.

A global default flow disaggregation method is set by *DFMETH* in *JU* record field 2. *DFMETHOD(cp)* is assigned *DFMETH* for all control points unless otherwise specified on *DC* records in the *DIF* file for individual control points. The *JU* record *DFMETH* default is overridden by *DC* record *DFMETHOD(cp)* for individual control points. Option 4 is the default for the global default *DFMETH*. Flow disaggregation option 4 is set as the global default by an entry of 0 or 4 in *JU* record field 2 or a blank *JU* record field 2.

Flow disaggregation option 4 requires that daily pattern hydrographs are provided as input. The selection of the default DFFILE option 1 in *JU* record field 3 means that the *DF* record daily flow pattern hydrographs are read from the DSS hydrology input file. The eight control points for which *DF* records of daily flows are read from the DSS file are listed on a *DF* record following the *JU* record in the DAT file reproduced as Table 7.3.

Control points Whit, WacoG, High, Belton, Grang, Camer, Bryan, and Hemp are listed on the *DF* record in the DAT file. *SIMD* terminates with an error message if *DF* records of 1940-2017 daily flows at these eight control points are not found in the DSS file. *SIMD* searches the DSS file for *DF* records for only these eight control points, ignoring *DF* records with other control point identifiers or any other records stored in the DSS file.

The DSS file contains no *DF* records for control points PK, WacoL, and George. Daily flows at the other control points with *DF* records are repeated at these three control points which have no *DF* records. The automated procedure in *SIMD* for repeating daily flows at multiple control points is described on page 28 of Chapter 2. The automated procedure consists of using flows at the nearest downstream control point if available, otherwise finding flows at the nearest upstream control point, and lastly if necessary using flows from another tributary. The automated procedure may be over-ruled at individual control points by *DC* records.

The *SIMD* automated procedure assigns daily flows at control point PK by repeating the *DF* record flows at Whit (nearest downstream control point) read from the DSS file. Daily flows at Grang are also automatically repeated as the daily pattern hydrograph used to disaggregate monthly naturalized flows at control point George.

Naturalized flows at control point WacoL represent inflows to Waco Lake. Daily flow data are not available for control point WacoL. The DIF file reproduced as Table 7.4 contains the following *DC* record.

DC WacoL 4 Belton

DF records for control point Belton read from the DSS file are repeated at control point WacoL. If this *DC* record is removed, the *DF* record daily flows at downstream control point WacoG from the DSS file would be automatically repeated by *SIMD* for use as the daily flow pattern hydrograph at control point WacoL. However, the *DC* record is used because the stream flows at control point Belton are considered more representative of flows at WacoL.

Default DFMETH option 4 is applied to all control points unless otherwise specified for individual control points by DFMETHOD(cp) on *DC* records. Option 4 could also be specified for all control points by inserting the following *DC* record in the DIF file.

DC Hemp 2 4

REPEAT=2 means that the *DC* record parameters are automatically repeated for all control points upstream of DCID(cp)=Hemp unless changed by other *DC* records.

Daily Flow Pattern Hydrographs in the Hydrology Input DSS File

The daily flow hydrographs for the eight control points are taken directly from the daily Brazos WAM, which includes daily flow hydrographs for 58 control points which are used to

disaggregate monthly naturalized flows to daily at over 3,700 control points [7]. The 1940-2017 daily flows at the 58 sites were compiled by combining observed daily flows at USGS gages with 1940-1997 unregulated daily flows at 37 sites obtained from a U.S. Army Corps of Engineers Fort Worth District modeling system. *HEC-DSSVue* was employed to compile the Brazos WAM daily flow dataset.

Pre-2018 versions of *SIMD* required that daily flows be stored in the DIF file. The option of storing daily flows in the DSS file was introduced in the 2018 version of *SIMD*. *DF* record daily flows can optionally be stored in either the DSS hydrology input file or the DIF file, but the DSS file is the recommended option. The DSS hydrology input file and *HEC-DSSVue* greatly enhance the compilation and employment of *DF* record daily flows.

DF records are compiled, manipulated, updated, analyzed, and organized using *HEC-DSSVue*. The *SIM/SIMD* hydrology DSS file with filename rootHYD.DSS optionally contains all monthly time series input (*IN*, *EV*, *HI*, *FA*, *TS* records) as well as the *DF* record daily flows. WRAP applications of HEC-DSS and the *HEC-DSSVue* component of HEC-DSS are described in Chapter 6 of the *Users Manual*.

Flood Control Reservoir Operations

The 28 *WR* record and two *IF* record water rights in the original example from the *Fundamentals Manual* remain unchanged in the daily version of the simulation input dataset. The conservation pools of the six reservoirs continue to be operated in the daily WAM the same as in the monthly WAM. The monthly *SIM* has no features for modeling flood control operations. Inflows pass through a reservoir instantaneously within the monthly computational time step without storage whenever the reservoir is full to conservation pool capacity. *SIMD* includes features activated by *FR*, *FF*, *FV*, and *FQ* records for simulating flood control operations as described in Chapter 5.

Five of the six reservoirs include designated flood control pools modeled in *SIMD* with *FR/FF* records as controlled flood control storage. Possum Kingdom (the sixth reservoir) includes surcharge storage capacity modeled with *FV/FQ* records as a flood control pool that attenuates flood flows to at least some degree though not considering downstream flows.

A system consisting of Belton, Granger, Georgetown, Whitney, and Waco Reservoirs is operated to control flood flows at the WacoG, Bryan, Hemp, and Camer control points as well as at the dam sites. These selected flood index locations represent the river system. Flood control pools are defined in Table 7.7. Flood control operations for the five-reservoir system are based on the maximum allowable flood flow levels listed in Table 7.8 and maximum flood pool releases listed in Table 7.7. These data defining operating rules are input on the *FR* and *FF* records shown in boldface in Table 7.3.

The remaining reservoir, Possum Kingdom (PK), has no designated controlled flood control pool, but like most typical water supply reservoirs, contains uncontrolled surcharge storage capacity above its top of conservation pool. Attenuation occurs as inflows exceed the outflow capacity of the outlet structures at the current storage level. Surcharge storage in Possum Kingdom Lake is modeled using the *FV* and *FQ* records included in the DAT file of Table 7.3.

Table 7.7
Flood Control Reservoir Operations Criteria on *FR* Records

Reservoir	Top of Conservation Pool (acre-feet)	Maximum Release Rate from Flood Control Pool		<u>FR Record Levels Defining Flood Pool</u>		
		Instantaneous (ft ³ /s)	<i>FR</i> Field 8 (ac-ft/day)	Field 9 Top of FC (acre-feet)	Field 10 <i>FV/FQ</i> (acre-feet)	Field 11 Bottom of FC (acre-feet)
Possum Kingdom	570,240	not used	not used	665,540	570,240	570,240
Whitney	627,100	25,000	49,600	2,000,000	not used	627,100
Waco	192,100	20,000	39,700	726,400	not used	192,100
Belton	457,600	10,000	19,800	1,091,320	not used	457,600
Georgetown	37,100	4,000	7,930	130,800	not used	37,100
Granger	65,500	10,000	19,835	244,200	not used	65,500

Table 7.8
Flood Control Operating Criteria on *FF* Records

Control Point	Flood Flow Limit		
	(ft ³ /s)	(acre-feet/day)	(ac-ft/year)
WacoG	50,000	99,170	36,200,000
Bryan	60,000	119,010	43,440,000
Hemp	60,000	119,010	43,440,000
Camer	10,000	19,835	7,240,000

As previously noted, the storage volume versus surface area tables (*SV* and *SA* records) in the DAT file used by *SIMD* in evaporation computations are extended in this example to include the flood control pools of the five flood control reservoirs and surcharge pool of Possum Kingdom Reservoir. The storage volume versus elevation table (*PV* and *PE* records) used in the Whitney hydropower computations is likewise extended higher to cover flood control storage.

Controlled (Gated) Flood Control Operations of Five Reservoirs

Operation of Whitney, Waco, Belton, Granger, and Georgetown Reservoirs for flood control is based on flow levels at gaging stations at the WacoG, Bryan, Hemp, and Camer control points and in the river just downstream of the dams. The flood control pools defined in Table 7.7 are emptied as quickly as possible without contributing to stream flows exceeding the limits specified in Table 7.8. Maximum non-damaging flow rates in cubic feet per second (cfs) are provided on *FF* records. In this example, maximum allowable flows are constant as specified on the *FF* records. Drought (storage) indices defined by *DI*, *IS*, *IP*, and *IM* records can be applied with flood flow *FF* records similarly to their application with *WR* record water right diversion targets. The flood flow limits can be varied as a function of reservoir storage as defined by a *DI/IS/IP* record storage index. However, this option is not applied in this example.

Maximum release rates from the flood control pools are shown in Table 7.7 and entered in *FR* record field 7 in units of cfs. These *FR* record maximum limits on releases from the flood control pool are equivalent to *FF* record maximum stream flow rates but are applied at the individual dam in the current day only without consideration of future forecasted flows.

Flow forecasting with reverse routing is applied by *SIMD* in making storage and release decisions. The option of allowing the forecast period to be automatically determined by *SIMD* is adopted. Lag and attenuation routing parameters are provided on *RT* Records.

The default *WRMETH* option 1 is selected in *JU* record field 4. In the *SIMD* simulation computations, changes in river flows caused by flood control operations in preceding time steps are placed at the beginning of the priority sequence. Effects of operation of each flood control reservoir on flood control operations of the other reservoirs is typically more accurately modeled by circumventing the priority system in this manner with *WRMETH* option 1. However, flood control storage and releases also affect flows available to *WR* record water supply rights.

Storage and release priority numbers of 910000 and 930000 are entered on the *FR* records for each of the five flood control reservoirs, making *FR* record flood control operations junior in the simulation computational sequence to all *WR* and *IF* record water rights. *FR* record fields 11 and 12 are blank, activating defaults of 1.0 and 0.0 for the factors *M* and *A* in Equation 5.4. Thus, multiple-reservoir release decisions are based on balancing the flood control storage contents as a percent of capacity in each of the five reservoirs.

The order in which the *FR* records are placed in the *DAT* file also affects simulation results. The reservoir with *FR* record listed first is considered first if the Eq. 5.4 rank index is the same for all reservoirs in a particular day. An example of this situation is a day in which all reservoirs are at top of conservation pool (bottom of flood control pool) at the beginning of the day. The order of the reservoirs in the simulation computations may significantly affect the allocation of flood waters between the different flood control pools.

Outlet Structures with Specified Gate Openings or without Gates

Possum Kingdom Reservoir has no controlled flood control storage. Surcharge storage above the top of conservation pool in Possum Kingdom Reservoir is modeled as a storage versus outflow table entered on *FV* and *FQ* records. *FR* record storage and release priorities of 900000 and 910000 make the *FV/FQ* record based flood release computations senior to and thus performed before operation of the five flood control reservoirs.

The storage volume versus outflow discharge (rating curve) table defined by a pair of *FV* and *FQ* records simulate outlet structures with no gates or with a specified fixed gate opening. The only application of *FV* and *FQ* records in this example consists of modeling the surcharge storage above the top of conservation pool of Possum Kingdom Reservoir. Water supply reservoirs, with no designated flood control pools, typically contain surcharge storage during periods of high flows spilling over or through spillways when the conservation pools are full. Effects of this surcharge storage on attenuating flow hydrographs is simulated by *FV/FQ* records. *FV/FQ* storage-outflow tables could also be used, along with the *FR* and *FF* record operations, in modeling the five flood control reservoirs, but to simplify the example are not.

FV/FQ record storage-outflow relationships are not incorporated in the *SIMD* DAT file for the five flood control reservoirs in this example. Reservoir release decisions are controlled by the river flow capacities at the dams and downstream gaging stations (*FR* and *FF* records) rather than the maximum flow capacities of the concrete outlet structures at the dams (*FV/FQ* records). *FV* and *FQ* records could be added for these five reservoirs for two different purposes:

1. modeling surcharge storage above the top of flood control pool and
2. modeling the maximum release capacity of outlet structures for releases from the designated controlled (gated) flood control pool.

The storage-outflow relationship provided by a pair of *FV* and *FQ* records are applied differently depending on whether the storage level rises above FCGATE. In the uncontrolled pool above FCGATE, releases depend solely on the *FV/FQ* record storage-outflow relationship. Without *FV/FQ* records, outflow equals inflow whenever the storage contents exceeds FCGATE. In the controlled pool below FCGATE, the *FV/FQ* record storage-outflow relationship provides a maximum limiting release capacity. Releases may be less than this upper discharge capacity limit if so dictated by *FF* record operations.

SIMD Simulation Output Files

Table 1.2 of Chapter 1 lists the ten types of output files created by both *SIM* and *SIMD* and the three additional types of output files created only by *SIMD*. The presentation of the illustrative example WAM in this manual includes the *SIMD* output files listed in Table 7.9. The remainder of Chapter 7 deals with simulation results recorded in MSS, SMM, OUT, SUB, and DSS files. The AFF file is employed and discussed in Chapter 9. The AFF file contains annual series of maximum daily naturalized and regulated flows and end-of-day reservoir storage volumes designed for use in flood frequency analyses.

Table 7.9
Selected *SIMD* Output Files

File	File Contents	Input Parameters Specifying Contents
MSS	monthly and daily message file	<i>JD</i> record field 4 (ICHECK)
SMM	additional daily message file	<i>JT</i> record fields 7, 8, 9, 10
OUT	monthly simulation results	<i>OF</i> record field 2 (DSS(2))
SUB	daily simulation results	<i>JD</i> record 5, 6 and <i>JT</i> record fields 11
DSS	monthly and daily simulation results	<i>JO</i> field 2, <i>JU</i> field 3, <i>OF</i> fields 4, 5
AFF	annual flood frequency analysis series	<i>JT</i> record field 6 (AFF)

The message files with filename extensions MSS and SMM are always automatically created with execution of *SIMD*. Some of the contents of the MSS and SMM files are controlled by input parameters listed in the last column of Table 7.9. The *SIMD* optional OUT, SUB, DSS, and AFF files are activated by the parameters listed in the last column of Table 7.9. Simulation results can be overwhelmingly massive. *SIM/SIMD* output is controlled and organized employing options specified by input parameters on *JD*, *JO*, *JT*, *OF* records and other records.

SIM/SIMD Message MSS File

A message file with filename extension MSS is always automatically created by both *SIM* and *SIMD*. The *SIMD* message MSS file for the daily example is reproduced as Table 7.10. The *SIM* message MSS file is reproduced in Appendix A of the *Fundamentals Manual*. The trace messages track the *SIM* and *SIMD* operations sequentially through the progression of program execution focusing primarily on reading input data and recording simulation results.

Display of warning and error messages is the other primary role of the MSS file. The MSS file of Table 7.10 has no warning or error messages indicating that the *SIMD* warning and error check routines detected no problems in this particular execution of *SIMD*.

Additional Daily SIMD Message SMM File

SIMD creates an additional message file with filename extension SMM that provides information regarding the daily simulation computations. Four types of optional tables can be created in the SMM file as specified by selection parameters DCSMM, RFASMM, APRDSMM, and RTGSMM in *JT* record fields 9, 10, 11, and 12. The following SMM file tables created pursuant to these input *JU* record entries (Table 7.3) are presented as Tables 11, 12, 13, and 14.

DCSMM=2	Table 7.11	Flow Disaggregation Tables
RFASMM=2	Table 7.12	Delivery Factor and Routing Factor Array (RFA) Tables
ARDSMM=2	Table 7.13	Water Rights Summary Table with Forecast Periods
RTGSMM=2	Table 7.14	Routing Adjustments by Control Point Table

Pulse flow quantities are recorded in the SMM file if specified by PFSMM on the *PF* record as discussed in Chapter 8. A list of water rights meeting *SC* record selection criteria is recorded in the SMM file by SCM=2 in *SC* record field 11 as noted in the *Users Manual*.

The two flow disaggregation tables in Table 7.11 are included in the SMM file as specified by DCSMM option 2 in *JT* record field 9. Definitions of the quantities tabulated in the two tables are provided with the tables. The tables confirm that option 4 is used to disaggregate naturalized monthly flows at all 11 control points and show the control point sources of the *DF* record daily flow pattern hydrographs. The January 1, 1940 and December 31, 2017 daily flows are tabulated to facilitate confirmation of correct *DF* records in the DSS file.

The ten delivery and routing factor array tables created by *SIMD* in the SMM file are shown in Table 7.12. The SMM file contains a table for each of the ten control points for which routing is applied. The tables for control points PK, Whit, and WacoL are reproduced in Table 7.12. The top portion of each table shows the delivery factor (DF) for each reach and cumulative delivery factors (CDFs) used to account for channel losses. The routing factors are tabulated as the bottom portion of each of the individual control point tables in Table 7.12.

Streamflow depletions for diversions and filling reservoir storage, reservoir releases, and return flows are propagated to downstream control points. Channel losses and routing are two different processes modeled by different algorithms. Channel losses are applicable to both monthly *SIM/SIMD* and daily *SIMD* simulations. Lag and attenuation modeled by the routing algorithm are applicable only to daily *SIMD* simulations.

Table 7.10
SIMD Message MSS File

WRAP-SIMD Message MSS File

```

*** Starting to read file DailyCh7.DAT
*** JD record was read.
*** JO record was read.
*** OF record was read.
*** JT record was read.
*** JU record was read.
*** DF record was read.
*** Starting to read UC records.
*** Finished reading UC records.
*** Starting to read CP records.
*** Finished reading CP records.
*** Starting to read water right IF, WR, FF, FR records.
*** Finished reading IF/WR records.
*** Starting to read FV/FQ records.
*** Finished reading FV/FQ records.
*** Starting to read SV/SA records.
*** Finished reading SV/SA records.
*** Starting to read PV/PE records.
*** Finished reading PV/PE records.
*** Following input to be read later from DSS file:
      IN and EV records (JO record INEV option 6)
      DF record daily flows (JU record default DFFILE)
*** Finished reading file DailyCh7.DAT
*** Checking for the SIMD file DailyCh7.DIF
*** Opened file DailyCh7.DIF
*** Starting to read input data from the DIF file.
*** Finished reading the input data from file DailyCh7.DIF
*** Starting to open remaining files.
*** Opened file DailyCh7.OUT
*** Opened file DailyCh7.SUB
*** Finished opening text (non-DSS) files.
-----DSS---ZOPEN: Existing File Opened, File: DailyCh7HYD.dss
                   Unit: 25; DSS Versions - Software: 6-WA, File: 6-QF
*** Starting to read daily flows from DSS file.
*** Number of control points with daily flows to be read from the DSS file = 7
*** Finished reading flows from DSS file.
-----DSS---ZCLOSE Unit: 25, File: DailyCh7HYD.dss
                   Pointer Utilization: 0.13
                   Number of Records: 784
                   File Size: 2235.3 Kbytes
                   Percent Inactive: 0.0

-----DSS---ZOPEN: Existing File Opened, File: DailyCh7HYD.dss
                   Unit: 25; DSS Versions - Software: 6-WA, File: 6-QF
*** Starting to read monthly flows from DSS file.
    Number of control points = 11
*** Finished reading flows from DSS file.
*** Starting to read evaporation from DSS file.
    Number of control points = 6
*** Finished reading evaporation from DSS file.
-----DSS---ZCLOSE Unit: 25, File: DailyCh7HYD.dss
                   Pointer Utilization: 0.13
                   Number of Records: 784
                   File Size: 2235.3 Kbytes
                   Percent Inactive: 0.0

*** Finished ranking water rights in priority order.

```

Table 7.10 MSS File Continued

```

*****
System components counted from input file:
  11 control points (CP records)
  11 primary control points (INMETHOD=1)
    6 control points with evap input (CPEV=blank)
    6 reservoirs
    6 flood reservoir FR records
    4 flood flow FF records
    2 instream flow IF records
  28 water right WR records
    3 system water rights
    1 hydropower rights
    6 sets of water use coefficients (UC records)
    6 storage-area tables (SV/SA records)
    1 flood storage-outflow tables (FV/FQ records)
    1 storage-elevation tables (PV/PE records)
*****
Daily simulation information:
  8 control points with daily flows input in hydrology DSS file.
  6 control points form the longest flow path to the outlet.
  10 control points have routing coefficients in the DIF file.
  5 control points form the longest routing chain to the outlet.
  12 forecast days are required for the longest routing chain with normal flow parameters.
  25 future time steps are covered during the forecast simulation.
*****
*** Beginning annual loop.
*** End of input data trace.
*** End of input data trace.
WARNING: Reservoir storage and evaporation computations did not converge to within
         stop criteria in 50 iterations for water right FR-STORAGE-2
         Reservoir: Whit ; CP: Whit ; Year: 1990; Month: 5; Final Evap: 640.31
         Begin Storage:1095856.75; 49th End Storage:1095160.75; 50th End Storage adopted:1095160.62
*** Writing simulation results in DSS file for DSS(3) option 2.
*** Beginning to write simulation results to DSS file.
-----DSS---ZOPEN: Existing File Opened, File: DailyCh7.dss
                   Unit: 26; DSS Versions - Software: 6-WA, File: 6-WA
*** Beginning control point output to DSS file.
*** Finished control point output to DSS file.
*** Beginning water right output to DSS file.
*** Finished water right output to DSS file.
*** Finished writing simulation results to DSS file.
-----DSS---ZCLOSE Unit: 26, File: DailyCh7.dss
                   Pointer Utilization: 2.22
                   Number of Records: 18060
                   File Size: 31858.4 Kbytes
                   Percent Inactive: 0.0
*** Writing monthly totals of daily simulation results in DSS file for DSS(3) option 2.
*** Beginning to write simulation results to DSS file.
-----DSS---ZOPEN: Existing File Opened, File: DailyCh7.dss
                   Unit: 26; DSS Versions - Software: 6-WA, File: 6-WA
*** Beginning control point output to DSS file.
*** Finished control point output to DSS file.
*** Beginning water right output to DSS file.
*** Finished water right output to DSS file.
*** Finished writing simulation results to DSS file.
-----DSS---ZCLOSE Unit: 26, File: DailyCh7.dss
                   Pointer Utilization: 2.22
                   Number of Records: 18060
                   File Size: 31858.4 Kbytes
                   Percent Inactive: 0.0

Date:           01/22/2021
Beginning Time: 10:34:11
Ending Time:    10:48:36

***** Normal Completion of Program WRAP-SIMD *****

```

Table 7.11
Flow Disaggregation Tables from *SIMD* Message SMM File

Flow Disaggregation Parameters from JU, DF, and DC Records

CPID	DFMETHOD	DFID	BEGYR	BEGMT	ENDYR	ENDMT	LAG	X	M	A
PK	4	Whit	1940	1	2017	12	0	1.00	1.00	0.0
Whit	4	Whit	1940	1	2017	12	0	1.00	1.00	0.0
WacoL	4	Belton	1940	1	2017	12	0	1.00	1.00	0.0
WacoG	4	WacoG	1940	1	2017	12	0	1.00	1.00	0.0
High	4	High	1940	1	2017	12	0	1.00	1.00	0.0
Belton	4	Belton	1940	1	2017	12	0	1.00	1.00	0.0
George	4	Grang	1940	1	2017	12	0	1.00	1.00	0.0
Grang	4	Grang	1940	1	2017	12	0	1.00	1.00	0.0
Camer	4	Camer	1940	1	2017	12	0	1.00	1.00	0.0
Bryan	4	Hemp	1940	1	2017	12	0	1.00	1.00	0.0
Hemp	4	Hemp	1940	1	2017	12	0	1.00	1.00	0.0

Daily flow pattern hydrographs for 28490 days.

I = 1, NCPTS control points on CP records

J = 1, NDFCP control points with flows in DSS file

K = control point I from which flows are assigned

CPID(I,1) are control point identifiers from CP records.

DCID(I) are control point identifiers from DC records.

DFID(I)/DFID(K) indicates the source of the daily flows.

DSS under DFID(K) indicates flows are read from DSS file.

I	J	K	CPID(I,1)	DCID(I)	DFID(I)	DFID(K)	1st Flow	Last Flow
1	1	2	PK		Whit	Whit	455.3	165.3
2	1	2	Whit		Whit	DSS	455.3	165.3
3	4	6	WacoL	WacoL	Belton	Belton	40.2	406.6
4	2	4	WacoG		WacoG	DSS	494.6	667.6
5	3	5	High		High	DSS	579.5	861.6
6	4	6	Belton		Belton	DSS	40.2	406.6
7	5	8	George		Grang	Grang	14.4	697.0
8	5	8	Grang		Grang	DSS	14.4	697.0
9	6	9	Camer		Camer	DSS	151.6	3387.3
10	7	10	Bryan		Bryan	DSS	843.3	2427.1
11	8	11	Hemp		Hemp	DSS	3865.0	5721.4

The delivery factor ($DF = 1.0 - F_{CL}$) is computed as a function of the channel loss factor F_{CL} entered on the control point *CP* record as described in Chapter 3 of the *Reference Manual*. Changes in stream flow are multiplied by the cumulative delivery factors shown in Table 7.12.

Routing of stream flow changes and incorporation of reverse routing in flow forecasting in the *SIMD* simulation based on a routing factor array (RFA) are described in Chapter 3 of this *Daily Manual*. Examples in Chapter 3 illustrate the concept of developing and applying a RFA of multipliers. Routing factor arrays are automatically developed and applied within the *SIMD* simulation. The *JT* record RFASMM allows the RFA array to be recorded for information as tables in the *SMM* file as illustrated by Table 7.12. The tables contain the factors used in the lag and attenuation routing computations for each routing reach from starting at the selected control point extending to the outlet. Routing factors that are used to route within the current time step are listed in the Day 0 row. Future day routing factors are listed on the rows for Day 1 or greater.

Table 7.12
First Three of Ten Routing Factor Array (RFA) Tables in *SIMD* Message SMM File

```

-----
CONTROL POINT ID          PK      Whit      WacoG      High      Bryan      OUTLET
-----
DELIVERY FACTOR          1.00000  0.93900  0.99100  0.99000  0.98600  0.97500
CUMULATIVE DF           1.00000  0.93900  0.93055  0.92124  0.90835  0.88564
-----
LAG                      6.040    1.000    1.070    1.810    1.980
ATTENUATION              1.000    1.000    1.000    1.000    1.000
-----
ROUTING      DAY 0      1.00000  0.00000  0.00000  0.00000  0.00000  0.00000
FACTOR      1      0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
ARRAY (RFA) 2      0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
             3      0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
             4      0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
             5      0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
             6      0.00000  0.93900  0.00000  0.00000  0.00000  0.00000
             7      0.00000  0.00000  0.93055  0.00000  0.00000  0.00000
             8      0.00000  0.00000  0.00000  0.82480  0.00000  0.00000
             9      0.00000  0.00000  0.00000  0.09645  0.16883  0.00000
            10     0.00000  0.00000  0.00000  0.00000  0.73951  0.00000
            11     0.00000  0.00000  0.00000  0.00000  0.00000  0.17607
            12     0.00000  0.00000  0.00000  0.00000  0.00000  0.70957
-----

```

```

-----
CONTROL POINT ID          Whit      WacoG      High      Bryan      OUTLET
-----
DELIVERY FACTOR          1.00000  0.99100  0.99000  0.98600  0.97500
CUMULATIVE DF           1.00000  0.99100  0.98109  0.96735  0.94317
-----
LAG                      1.000    1.070    1.810    1.980
ATTENUATION              1.000    1.000    1.000    1.000
-----
ROUTING      DAY 0      1.00000  0.00000  0.00000  0.00000  0.00000
FACTOR      1      0.00000  0.99100  0.00000  0.00000  0.00000
ARRAY (RFA) 2      0.00000  0.00000  0.98109  0.00000  0.00000
             3      0.00000  0.00000  0.00000  0.18121  0.00000
             4      0.00000  0.00000  0.00000  0.78615  0.00000
             5      0.00000  0.00000  0.00000  0.00000  0.18895
             6      0.00000  0.00000  0.00000  0.00000  0.75422
-----

```

```

-----
CONTROL POINT ID          WacoL      WacoG      High      Bryan      OUTLET
-----
DELIVERY FACTOR          1.00000  1.00000  0.99000  0.98600  0.97500
CUMULATIVE DF           1.00000  1.00000  0.99000  0.97614  0.95174
-----
LAG                      0.260    1.070    1.810    1.980
ATTENUATION              1.000    1.000    1.000    1.000
-----
ROUTING      DAY 0      1.00000  0.74000  0.00000  0.00000  0.00000
FACTOR      1      0.00000  0.26000  0.69395  0.00000  0.00000
ARRAY (RFA) 2      0.00000  0.00000  0.29605  0.12955  0.00000
             3      0.00000  0.00000  0.00000  0.60755  0.00000
             4      0.00000  0.00000  0.00000  0.23904  0.13595
             5      0.00000  0.00000  0.00000  0.00000  0.58656
             6      0.00000  0.00000  0.00000  0.00000  0.22923
-----

```


Simulation Results DSS, SUB, and OUT Files

A *SIM* or *SIMD* monthly simulation steps through the 936 months of the 1940-2017 hydrologic period-of-analysis. A *SIMD* daily simulation steps through the 28,490 days of 1940-2017 which includes 58 years with 365 days and 20 years with 366 days. *SIMD* and *TABLES* automatically assign 29 days to February in leap years and 28 days in other years. The simulation results recorded in the OUT, SUB, and DSS files consist of time series of all the relevant simulation results variables for selected control points, water rights, and reservoirs.

Selections of control points, water rights, and reservoirs to include in the *SIMD* daily simulation results output is the same for the OUT, SUB, and DSS files and are controlled by OUTCP2 and OUTWR2 in *JT* record fields 2 and 3 and *C2*, *W2*, *G2*, and *R2* records. Selections of control points, water rights, and reservoirs to include in the OUT and DSS files for a *SIM* or *SIMD* monthly simulation are controlled by OUTCP and OUTWR in *JD* record fields 3 and 4 and *CO*, *WO*, *GO*, and *RO* records.

For the example, the output options selected on the *OF* and *JT* records in the DAT file of Table 7.3 consists of DSS(1)=1, DSS(3)=2, CPOUT2=1, and OUTWR2=2. Of course, these selections can be easily changed to other alternative options. The 1 entered for CPOUT2 and 2 for OUTWR2 on the *JT* record result in output records for all control points and all water rights being included in the DSS, SUB, and OUT files. Reservoir output records (controlled by *RO* and *R2* records) are not included in the files. The SUB file is automatically created for all daily simulations. DSS(1) option 1 on the *OF* record activates the OUT file. DSS(3) options 1, 2, or 3 create a DSS output file.

OF record DSS(3) option 2 means that both monthly and daily simulation results are included in the DSS file. In a daily simulation with monthly totals included in the DSS and OUT files as well as daily quantities in the DSS and SUB files, the control points, water rights, and reservoirs selected for the daily results are also adopted for the monthly summations of daily results. This is the case for the example.

A monthly OUT and daily (sub-monthly) SUB file have the same format. For the example, the OUT file contains output records for eleven control points and 29 water rights for each of the 936 months of the simulation, and the SUB file contains output records for each of the 28,490 days. The OUT file may be used to store either monthly results for a monthly simulation or monthly totals from a daily simulation.

OUT and SUB files, if created, contain all simulation results variables for the selected control points, water rights, and/or reservoirs. The OUT and SUB files cannot be limited to a user-selected sub-group of variables. The OUT and SUB files always include all 42 of the simulation results output variables for user-selected control points, water rights, and reservoirs in the format defined by Tables 5.1, 5.2, 5.3, 5.4, and 5.5 of Chapter 5 of the *Reference Manual*. However, conversely, DSS(4) on the *OF* record allows selection of any subset of the 42 simulation results variables for inclusion in the DSS file as noted in the next paragraph.

A list of 42 simulation results variables is provided with the *OF* record description in Chapter 3 of the *Users Manual*. DSS(4) options in *OF* record field 5 allow any or all of the 42

simulation results output variables to be included in the DSS file for the selected control points, water rights, and reservoirs. *OF* record field 5 is blank in the DAT file of Table 7.3, activating the default of a defined subset of the 42 simulation results variables being included in the DSS file. The DSS file includes six control point variables (NAT, REG, UNA, STO, TAR, SHT), five *WR* record water right variables (TAR, SHT, DIV, STO, DEP), and two *IF* record water right variables (IFT, IFS). Entering a -1 for DSS(4) in *OF* record field 5 would result in all 42 of the simulation results variables being included in the DSS file.

TABLES and HEC-DSSVue

The WRAP program *TABLES* reads the OUT and SUB files and organizes the simulation results. Likewise, *HEC-DSSVue* reads the DSS file and organizes the simulation results. *TABLES* can also read and manipulate simulation results, which it then writes to a DSS file to be read with *HEC-DSSVue*. The USACE Hydrologic Engineering Center's program *HEC-DSSVue* is employed as an integral component of the WRAP software package.

Simulation results are organized, summarized, analyzed, and displayed with *HEC-DSSVue* and *TABLES*. *HEC-DSSVue* provides comprehensive data management and graphics capabilities not provided with *TABLES*. Conversely, *TABLES* provides capabilities not included in *HEC-DSSVue* for developing tables of water supply and hydropower reliability metrics, volume budgets, and simulation input and output summaries. Both *HEC-DSSVue* and *TABLES* provide similar statistical frequency analysis options.

TABLES is covered in Chapter 7 of the *Reference Manual* and Chapter 5 of the *Users Manual*. The *TABLES* time series, 6REL, 6FRE, 6FRQ, and 6RES input records dealing with daily *SIMD* simulation results are daily versions of the time series, 2REL, 2FRE, 2FRQ, and 2RES records for *SIM* or *SIMD* monthly simulation results. The 7FFA, 7VOL, and 7DAM records for flood frequency and flood damage analyses based on *SIMD* daily simulation results have no monthly counterparts. 2REL, 6REL, 2FRE, and 6FRE record analyses are included in the following Chapter 7 analyses. 7FFA record analyses are presented in Chapter 9.

The *TABLES* input TIN file records used to develop the statistical frequency and reliability metrics presented in the remaining sections of this chapter are shown in Table 7.15. The records are explained in detail in Chapter 5 of the *Users Manual*.

HEC-DSSVue allows large datasets of time series data to be conveniently managed, inventoried, searched, grouped, displayed, compared, mathematically manipulated, and statistically analyzed. The simulation results file with filename DailyCh7.DSS is included in the example datasets that accompany the WRAP software and manuals. The time series plots presented later in this chapter illustrate graphics capabilities. These plots were created with *HEC-DSSVue* and copied into the Microsoft Word document for this manual.

Massive simulation results can be efficiently explored with *HEC-DSSVue* by quickly selecting and plotting or tabulating numerous time series on the computer monitor without actually copying edited plots or tables into reports. Frequency graphs as well as time series graphs can be plotted in *HEC-DSSVue*. A flexible array of options for comparative analyses, mathematical operations, statistical analyses, unit conversions, and conversions between time

steps such as daily, monthly, and annual are provided by *HEC-DSSVue* as explained in detail in its *Users Manual* [8] and briefly in Chapter 6 of the *WRAP Users Manual* [2].

Table 7.15
TABLES Input TIN File

```

**          1          2          3          4          5
** 567890123456789012345678901234567890123456789012
**
**** Frequency tables for naturalized flows.
2FRE  1  0  2  2
IDEN  Camer    Hemp
6FRE  1  0 -2  2
2FRE  1  0 -2  2  0  1
6FRE  1  0 -2  2  0  1
**** Frequency tables for reservoir storage.
2FRE  4  0  6  3
IDEN   PK    Whit  WacoL  Belton  George  Grang
6FRE  4  0 -6  3
**** Water supply diversion reliability tables.
2REL
6REL
**** Frequency tables for regulated flows.
2FRE  2  0  2  3
IDEN  Camer    Hemp
6FRE  2  0 -2  3
2FRE  2  0 -2  3  0  1
6FRE  2  0 -2  3  0  1
**** Frequency tables for unappropriated flows.
2FRE  3  0  2  3
IDEN  Camer    Hemp
6FRE  3  0 -2  3
2FRE  3  0 -2  3  0  1
6FRE  3  0 -2  3  0  1
ENDF

```

WRAP applications of *HEC-DSSVue* are outlined in Chapter 6 of the *Users Manual* [2]. Daily and monthly *SIM* and *SIMD* simulation results are stored in the same DSS file. Pathname part E is 1DAY and 1MON for DSS records of daily and monthly time series data. *HEC-DSSVue* treats daily and monthly data in essentially the same manner. The daily flows in a *SIMD* input dataset and the daily *SIMD* simulation results are massive and can be managed much more efficiently as DSS records in DSS files than in text format in DIF, FLO, and SUB files.

The DSS output file with filename DailyCh7.DSS created by *SIMD* contains a total of 410 DSS records, which includes 205 records with 1940-2017 daily simulation results and 205 records with 1940-2017 monthly simulation results. Each record contains either 936 months of monthly totals or 28,490 days of daily quantities for a particular variable for a particular control point or water right. DSS records are inventoried and identified by pathnames consisting of parts A, B, C, D, E, and F. Six examples of pathnames for the 410 DSS records are as follows. These

DSS records contain naturalized stream flow (NAT) and reservoir storage (STO) volumes for control point Belton and diversion target (TAR) volumes for water right WR-8.

<u>Part A</u>	<u>Part B</u>	<u>Part C</u>	<u>Part D</u>	<u>Part E</u>	<u>Part F</u>
DAILYCH7	BELTON	NAT	31JAN1940-31JAN2017	1DAY	CPDAILY
DAILYCH7	BELTON	NAT	31JAN1940-31JAN2017	1MON	CP
DAILYCH7	BELTON	STO	31JAN1940-31JAN2017	1DAY	CPDAILY
DAILYCH7	BELTON	STO	31JAN1940-31JAN2017	1MON	CP
DAILYCH7	WR-8	TAR	31JAN1940-31JAN2017	1DAY	WRDAILY
DAILYCH7	WR-8	TAR	31JAN1940-31JAN2017	1MON	WR

Monthly and Daily Naturalized Stream Flows

A *SIM* or *SIMD* simulation employs two DSS files, an input file and an output file. The *SIMD* or *SIM* hydrology input DSS file for the example has the filename ExamplesHYD.DSS. The simulation results output DSS file has the filename DailyCh7.DSS. The HYD appended to the filename root DailyCh7 distinguishes the DSS input file from the DSS output file. The hydrology input DSS file filename root *Examples*, without the HYD appendage, is optionally entered in *OF* record field 13 (columns 61-92) to allow the basic DAT and output filename to vary between simulations without changing the DSS input filename. If *OF* record field 12 is left blank, the input DSS filename root by default must be the same as the DIS, EVA, and FLO files, which by default is the root of the DAT input file and OUT and DSS output files.

Naturalized monthly flow volumes in acre-feet (*IN* records), monthly net reservoir evaporation less precipitation depths in feet (*EV* records), and daily flow volumes in acre-feet (*DF* records) covering the January 1940 through December 2017 hydrologic period-of-analysis are stored in the hydrology input file with the filename ExamplesHYD.DSS. This DSS file contains a total of 24 records, which includes 11 *IN* records, 6 *EV* records, and 7 *DF* records. DSS pathname conventions are illustrated by the following pathnames for naturalized flows, evaporation-precipitation rates, and daily flows at control point Grang (Granger Reservoir).

EXAMPLES	GRANG	IN	01Jan1940-31Dec2017	1DAY
EXAMPLES	GRANG	EV	01Jan1940-31Dec2017	1DAY
EXAMPLES	GRANG	DF	01Jan1940-31Dec2017	1DAY

Sequences of 1940-2017 monthly naturalized flow volumes at 11 control points are provided on *IN* records in the hydrology input DSS file. Sequences of 1940-2017 daily flows at eight control points are provided on *DF* records in the hydrology input DSS file for use as daily pattern hydrographs in disaggregating the monthly flow volumes at the 11 control points to daily volumes. The disaggregation algorithm is based on distributing the *IN* record monthly volume for a month over the 28, 29, 30, or 31 days of the month in proportion to the *DF* record daily flows while preserving the monthly flow volume.

DF record flows at eight control points are used to disaggregate monthly flow volumes to daily at the eleven control points. The daily flows were originally compiled as mean daily flows in units of cubic feet per second (cfs). The daily flows input on *DF* records can be in cfs or any other units since they are being used within *SIMD* only as pattern hydrographs. The choice of units of the daily pattern hydrograph flows does not affect *SIMD* simulation results.

Though not necessary, the original *DF* record daily flows were converted from mean daily flows in cfs to daily flow volumes in acre-feet. *SIMD* was executed with the original *DF* record flows in cfs, and the daily naturalized flow volumes in acre-feet were recorded in the *SIMD* simulation results output DSS file. Employing *HEC-DSSVue*, the daily flow volumes in acre-feet are easily and quickly transferred to *DF* records in the hydrology input DSS file. Thus, the monthly and daily flows in the *SIMD* hydrology input DSS file as well as output DSS file are consistently all volumes in acre-feet. The daily flows are identical in the input and output files for the eight control points with *DF* records in the input file. The three other control points have naturalized daily flows in the output file but not in the input file.

HEC-DSSVue plots of daily and monthly naturalized flow volumes at the Cameron gage on the Little River (control point Camer) and Hempstead gage on the Brazos River (control point Hemp) are presented as Figures 7.2, 7.3, 7.4, and 7.5. Information regarding these two gage sites is found in Table 7.1. The plots illustrate the extreme flow variability characteristic of rivers throughout Texas. Monthly flows are highly variable. Daily flows are much more variable.

TABLES was applied with the first set of 2FRE and 6FRE records in the TIN file of Table 7.15 to compute the statistical frequency metrics tabulated in Table 7.16 for naturalized flows at control points Camer and Hemp. The metrics tabulated in Table 7.16 include means, standard deviations, and flow quantities associated with specified frequencies defined by the relative frequency formula (Eq. 7.1) where *m* is the rank and *N* is either the 936 months or 28,490 days of 1940-2017. Alternatively, *HEC-DSSVue* employs Equation 7.2 for these computations.

$$\text{Exceedance Frequency} = \frac{m}{N} (100\%) \quad (7.1)$$

$$\text{Exceedance Frequency} = \frac{m}{N + 1} (100\%) \quad (7.2)$$

The mean, standard deviation, and Eq. 7.1 frequency quantities tabulated in Table 7.16 are computed for either 936 monthly volumes or mean flow rates or 28,490 daily volumes or mean flow rates. All monthly and daily flow volumes in the *SIM* and *SIMD* simulation input, computations, and output are in units of acre-feet. *SIMD* disaggregates monthly volumes to daily volumes and sums daily volumes to obtain monthly volumes. Statistical frequency metrics for the series of 936 monthly naturalized flow volumes in acre-feet at control points Camer and Hemp, respectively, are tabulated in columns 2 and 6 of Table 7.16. Metrics for the series of 28,490 daily flow volumes in acre-feet are presented in columns 3 and 7. Statistics for 936 quantities consisting of monthly means in cfs (ft³/s) are presented in columns 4 and 8. Statistics for 28,490 daily means in cfs are presented in columns 5 and 9 of Table 7.16.

The effects of computational time interval on frequency metrics are illustrated by Figure 2.1 in Chapter 2 and also by a comparison of columns 4 versus 5 and columns 8 versus 9 of Table 7.16. For example, the median (50% exceedance frequency) of the 936 monthly means at Camer is 744.1 cfs compared to 469.8 cfs for the 28,490 daily means. The mean flows exceeded during 50% of the 936 months and 50% of the 28,490 days at Hemp are 3,699 and 2,474 cfs. The means of 1,844 cfs for the monthly mean flows and 1,841 cfs for daily mean flows at Camer are a little different because of the varying number of days in the 12 calendar months. The monthly and daily means of 7,390 and 7,378 cfs at control point Hemp are likewise not exactly the same. Monthly means exceed daily means for very low flows and vice versa for very high flows.

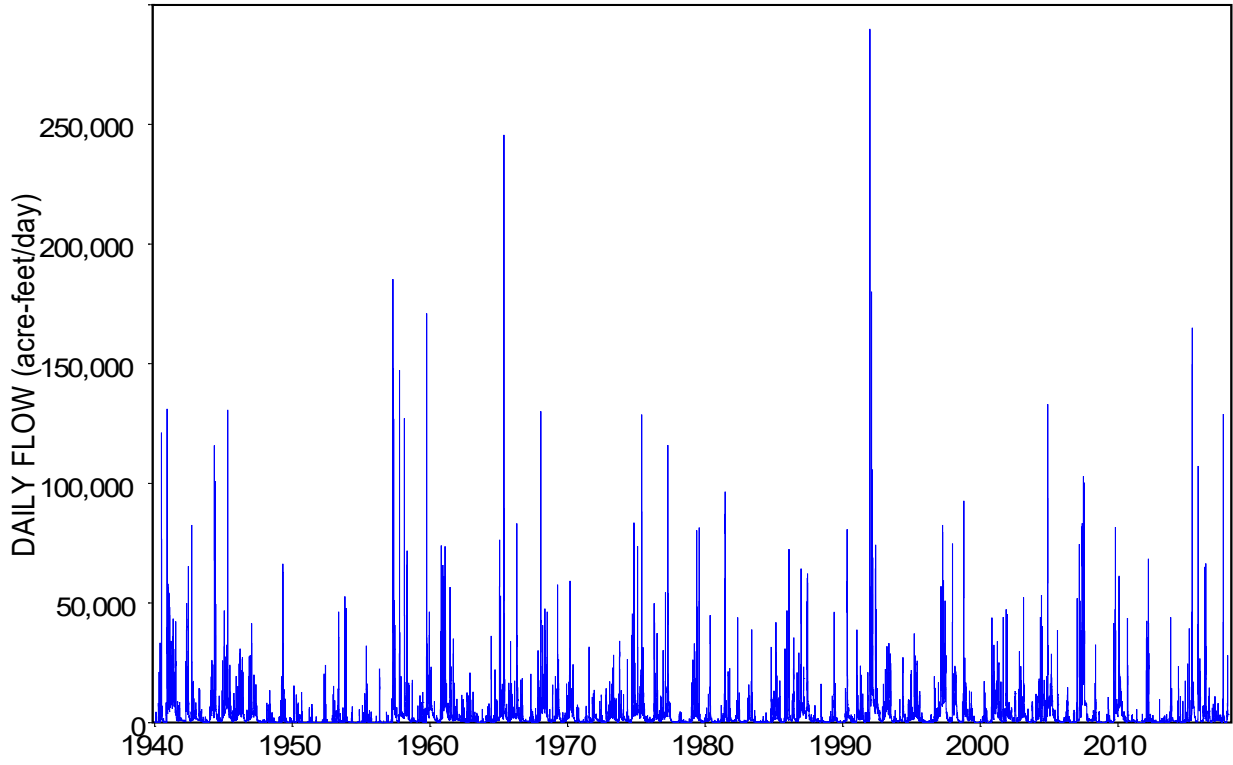


Figure 7.2 Daily Naturalized Flow at Control Point Camer in acre-feet/day

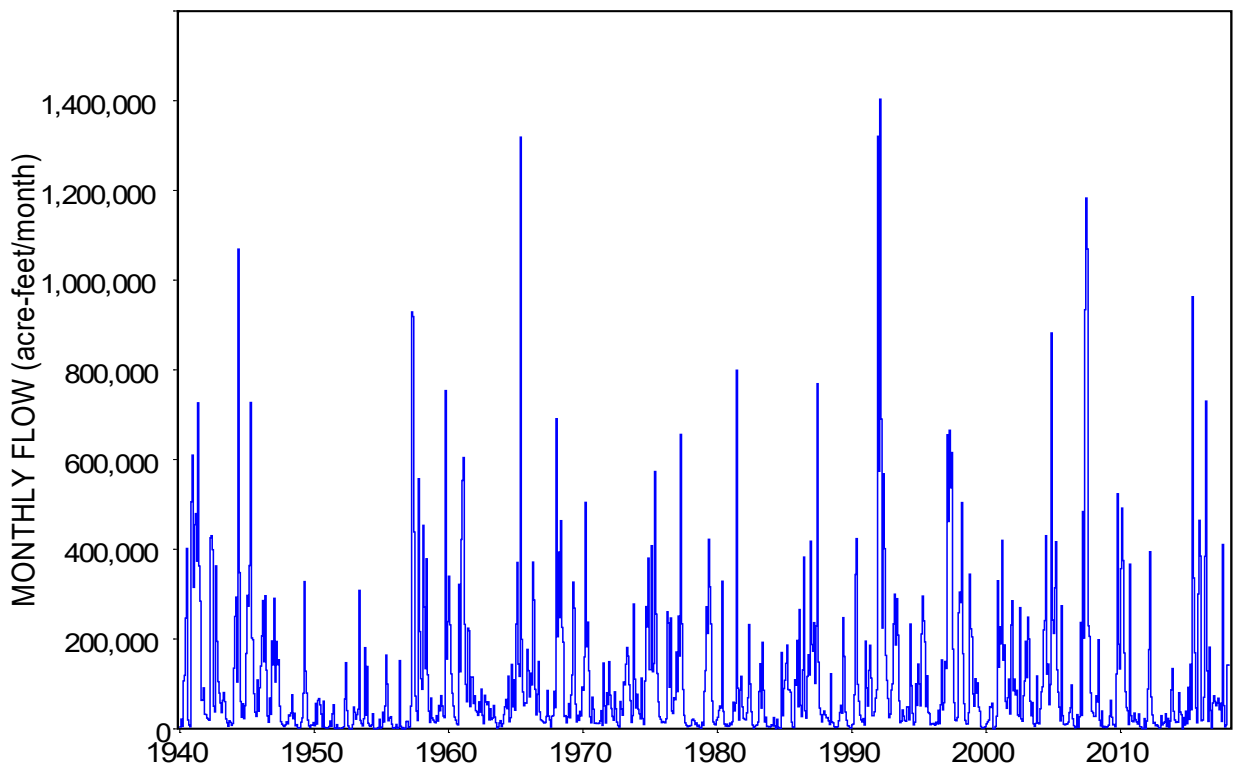


Figure 7.3 Monthly Naturalized Flow at Control Point Camer in acre-feet/month

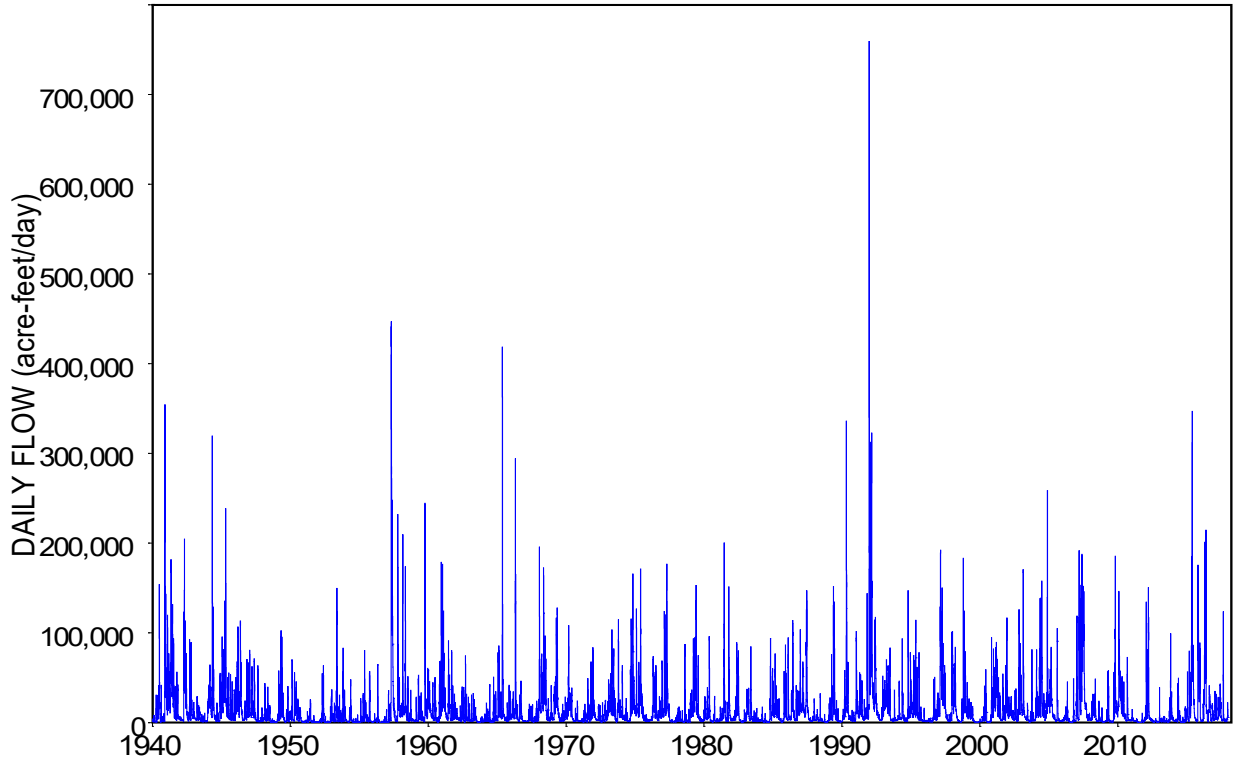


Figure 7.4 Daily Naturalized Flow at Control Point Hemp in acre-feet/day

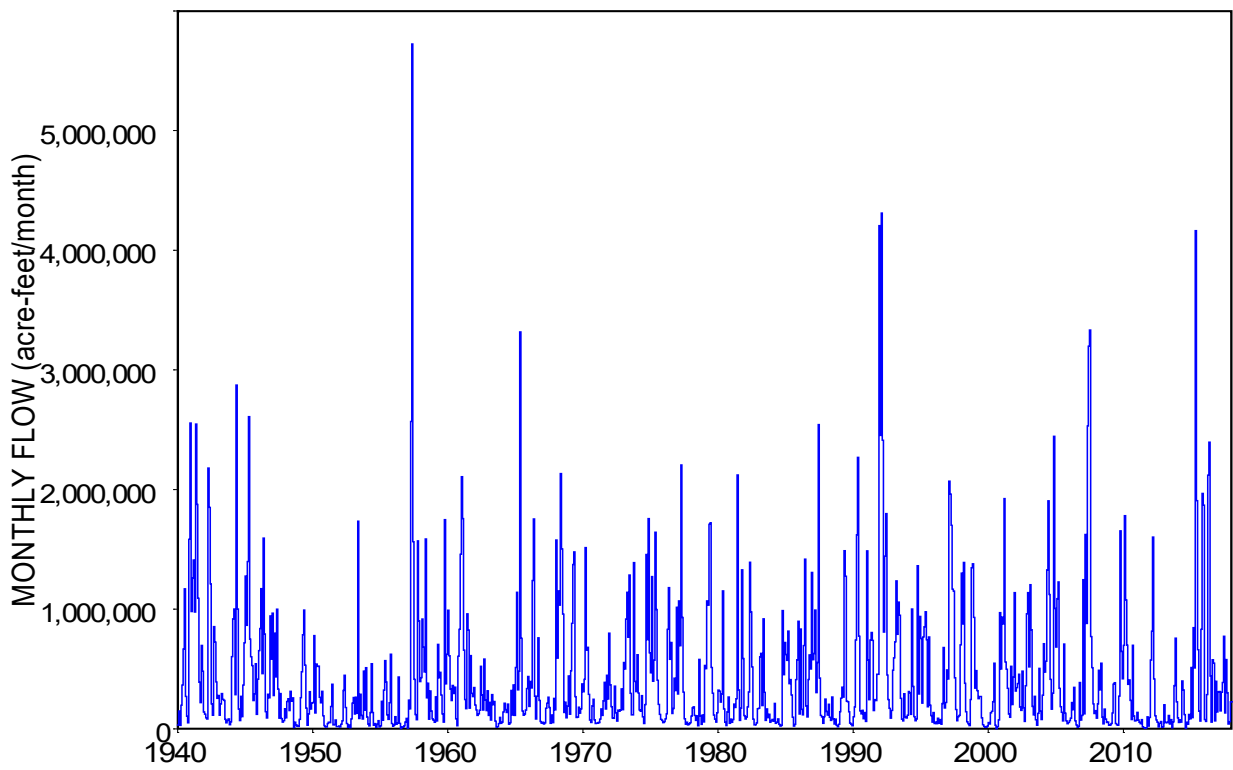


Figure 7.5 Monthly Naturalized Flow at Control Point Hemp in acre-feet/month

Comparative Analyses of Simulation Results

The results of the monthly *SIM* simulation are organized in the *Fundamentals Manual* using many of the different types of tables that can be created with *TABLES*. The *Fundamentals Manual* also includes plots developed with *HEC-DSSVue*. Selected capabilities of *TABLES* and *HEC-DSSVue* are applied to both monthly and daily *SIM* and *SIMD* simulation results in the remainder of the present Chapter 7 and the subsequent Chapters 8 and 9.

The remainder of Chapter 7 consists of comparative analyses of the monthly and daily results from four simulations, which are labeled FM, D1, D2, and D3. Simulation FM employs the original example monthly WAM presented in the *Fundamentals Manual*. Simulation D3 employs the complete DAT and DIF input files replicated as Tables 7.3 and 7.4. Simulations D1 and D2 omit selected input records from the DAT and DIF files of Tables 7.3 and 7.4.

The naturalized flows are identically the same in all four simulations. Only monthly naturalized flows are employed in the monthly simulation labeled FM. The monthly flows are disaggregated to daily in the daily simulations labeled D1, D2, and D3 based on daily pattern hydrographs. All four simulations employ the same hydrology input DSS file.

The naturalized flows of the example at the eleven control points listed in Table 7.1 are from the actual Brazos WAM. Actual storage capacities are employed in the model for six actual reservoirs. The diversion targets and other water rights input data are realistic but hypothetical, not representing any particular actual water right permits. Thus, although the example is hypothetical, the comparative analyses presented here provide meaningful illustrative insight into river flow and reservoir storage characteristics and water availability modeling.

Alternative Simulations

The four alternative simulations discussed in the remainder of this chapter are labeled FM, D1, D2, and D3 and are defined as follows.

- FM Monthly *SIM* simulation for the example presented in the *Fundamentals Manual*.
- D1 Daily *SIMD* simulation without forecasting, routing, and flood control.
- D2 Daily *SIMD* simulation with forecasting and routing but without flood control.
- D3 Daily *SIMD* simulation with forecasting, routing, and flood control.

Simulation FM uses a monthly computational time step and thus produces only monthly simulation results. Simulations D1, D2, and D3 are based on a daily computational time interval and generate daily results which are summed within *SIMD* to monthly quantities. The daily simulation results quantities produced by simulations D1, D2, and D3 are labeled D1d, D2d, and D3d in this chapter. The datasets of monthly summations are called D1m, D2m, and D3m. The alternative simulations are listed in Table 7.17 and discussed in the following paragraphs.

Detailed results for simulation FM are presented in the *Fundamentals Manual*. The monthly *SIM* simulation presented in this chapter produces the same results as the WAM in the *Fundamentals Manual* though employing the adjusted DAT file shown in Table 7.3. The *JD* record negative incremental flow adjustment *ADJINC* option is 7 and 6 (or 4), respectively, for the daily and monthly simulations. *ADJINC* options 4 and 6 yield the same results.

Table 7.17
Alternative Simulations

FM	Monthly <i>SIM</i> simulation for the example presented in the <i>Fundamentals Manual</i> .
D1	Daily <i>SIMD</i> simulation without forecasting, routing, and flood control. Daily and monthly simulation results from daily simulation D1 are labeled D1d and D1m. D1 input dataset consists of the FM input dataset with the following additions. Daily simulation is activated by addition of <i>JT</i> record to DAT file. Daily output is specified in <i>OF</i> and <i>JT</i> records in the DAT file. Daily flow pattern hydrographs on <i>DF</i> records in the hydrology input DSS file are accessed by <i>DF</i> records in the DAT file. Flow disaggregation is controlled by <i>DFMETH</i> on the <i>JU</i> record and specifications on the <i>DC</i> record in the DIF file.
D2	Daily <i>SIMD</i> simulation with forecasting and routing but without flood control. Daily and monthly simulation results from daily simulation D2 are labeled D2d and D2m. D2 input dataset consists of the D1 input dataset with the following additions. Negative incremental adjustment option is changed from 6 to 7 on <i>JD</i> record. Forecasting is activated by <i>FCST</i> on the <i>JU</i> record in the DAT file. Routing is activated by the <i>RT</i> records in the DIF file.
D3	Daily <i>SIMD</i> simulation with forecasting, routing, and flood control. The daily and monthly simulation results from daily simulation D3 are labeled D3d and D3m. D3 input dataset consists of the D2 input dataset with the following additions. Flood control is activated by <i>FF</i> , <i>FR</i> , <i>FV</i> , and <i>FQ</i> records in DAT file. <i>SV/SA</i> and <i>PV/PE</i> record tables are extended to include flood control pools.

A monthly simulation can be performed with *SIM* with a DAT file containing input records for a daily simulation, such as the DAT file of Table 7.3. *SIM* skips over daily input records in the DAT file, does not read the DIF file, and ignores the *DF* records in the DSS file. The *SIM* message MSS file includes warning messages indicating that DSS(3)=2 on the *OF* record was changed to DSS(3)=1 and the *JT*, *JU*, *DF*, *FF*, *FR* (with supporting *WS*), *FV*, and *FQ* records were skipped over without reading. *SIMD* has no option for skipping over these DAT file records, other than manually commenting (**) them out.

Simulation D1 was performed with the DAT file of Table 7.3 with the *FF*, *FR* and supporting *WS*, *FV*, and *FQ* records deactivated with asterisks (**) as the first two characters. Forecasting is deactivated by a zero for *FCST* on the *JU* record. The *JU* record has all defaults and is not needed. Routing is deactivated in simulation D1 by removal of the *RT* records in the DIF file. *ADJINC* option 6 is selected in *JD* record field 8 for both simulations D1 and FM.

Simulation D2 is based on the same input dataset as simulation D1 except forecasting is activated by *FCST* on the *JU* record, *ADJINC* is changed from 6 to 7 on *JD* record, and routing is activated by employing the *RT* records. Simulation D3 is based on the complete dataset. The only difference between simulations D3 and D2 is activation of the *FF*, *FR*, *FV*, and *FQ* records.

Simulations D1, D2, and D3 are all based on the monthly WAM employed in the FM simulation and add selected new optional features to the monthly WAM to simulate within-month daily variability as outlined in Table 7.17. The new features represent a step-by-step conversion of a monthly model to daily that reflects selected aspects of daily variability.

Simulation D1 is based on adopting a daily computational time step and disaggregating the monthly naturalized flow volumes to daily. The extreme variability inherent in stream flow is illustrated by the plots in Figures 7.2, 7.3, 7.4, and 7.5. Naturalized stream flows generally are the greatest though not only possible source of daily variability that may be modeled in a *SIMD* simulation. The example does not employ *SIMD* options to vary monthly water supply diversion targets and instream flow targets on a daily basis. Water right targets are distributed uniformly over the days of the month. Likewise, monthly-varying reservoir evaporation-precipitation rates are evenly distributed within each month within the daily WAM.

Simulation D2 is identical to D1 except routing and forecasting and ADJINC option 7 are activated. Forecasting is relevant only if routing is activated. Forecasting and routing greatly complicate the simulation computations. Estimates of values for routing parameters are inherently very approximate. The monthly WAM reflects the premise that the downstream effects of streamflow depletions for diversions and refilling storage propagate to the river system outlet within the same month. Routing allows the effects of flow changes due to diversions and refilling reservoir storage to reach downstream control points in the model one or multiple days later. Forecasting is employed along with routing to protect water availability for downstream senior water rights and to facilitate operating flood control pools based on flows at downstream control points. With forecasting activated with FCST on the *JU* record, the *JU* record parameters FPRD, APRD, WRMETH, and WRFCT, and associated complexities become relevant.

The issue of negative incremental naturalized flows must be addressed in either a monthly or daily WAM through selection of an ADJINC option in *JD* record field 8. The choice of ADJINC option can significantly affect simulation results of a monthly WAM. The effects of negative incremental flows and choice of ADJINC option affect the simulation results of a daily WAM even more than a monthly WAM. The effects of negative incremental flow adjustment computations and daily routing and forecasting computations are integrally related and complex.

Simulation D3 employs the complete DAT file of Table 7.3. Simulation D3 is identical to D2 except for the addition of reservoir operations for flood control. The storage capacities in Tables 7.7 and 7.18 for the six reservoirs include conservation pool capacities totaling 1,949,640 acre-feet and flood control pool capacities totaling 2,908,620 acre-feet. Flood control pools are maintained empty except immediately following infrequent flood events. Flood events typically occur over relatively short periods of time. The monthly *SIM* has no features for modeling operations of reservoir flood control pools. Whenever conservation storage is full to capacity, outflows are assumed to equal inflows in simulations D1 and D2 as well as in simulation FM.

Simulation Results for the Four Alternative Simulations

Simulation results are stored in DSS, OUT, and SUB files created by *SIM* or *SIMD*. The simulation results in the DSS file are organized, analyzed, and displayed using *HEC-DSSVue*. The simulation results in the OUT and SUB files are organized, analyzed, and displayed using

TABLES. Each *SIM* or *SIMD* simulation creates new OUT and SUB files containing only the results from that one simulation. *SIM* and *SIMD* over-write existing OUT and SUB output files unless filename roots are changed, and the results from multiple simulations cannot be stored in the same OUT and SUB files. Likewise, each execution of *TABLES* produces a new *TABLES* output TOU file which completely replaces any existing file with the same filename. However, results from multiple *SIM* and/or *SIMD* simulations can be written to the same DSS file.

As noted earlier in this chapter, a *SIMD* simulation with the DAT file replicated as Table 7.3 produces a DSS file with 410 records. This includes 205 records with 28,490 days (January 1, 1940 through December 31, 2017) of daily quantities for a particular variable for a particular control point or water right and corresponding 205 records with 936 monthly summations covering the 936 months of 1940-2017. Each of the 410 DSS records has a pathname with pathname parts A, B, C, D, E, and F as explained in Chapter 6 of the *Users Manual*. The pathname structure of the records is illustrated by the following pathnames of four records which contain end-of-day and end-of-month reservoir storage volumes (STO) for control point Wacol and daily and monthly streamflow depletions (DEP) for water right WR-3 at control point Whit.

<u>Part A</u>	<u>Part B</u>	<u>Part C</u>	<u>Part D</u>	<u>Part E</u>	<u>Part F</u>
DAILYCH7	WACOL	STO-CP	31JAN1940-31JAN2017	1DAY	CPDAILY
DAILYCH7	WACOL	STO-CP	31JAN1940-31JAN2017	1MON	CP
DAILYCH7	WHIT	DEP-WR	31JAN1940-31JAN2017	1DAY	WR-3
DAILYCH7	WHIT	DEP-WR	31JAN1940-31JAN2017	1MON	WR-3

Pathname part A is the root of the filename of the DAT and DSS files (DailyCh7.DAT and DailyCh7.DSS). With multiple simulations employing the same filename, individual DSS records with identically the same pathname as those already found in an existing DSS file are over-written (replaced), new records with different pathnames are added, and any other old records remain unchanged. Records can be quickly inventoried and grouped in *HEC-DSSVue*. Pathnames are conveniently revised individually or by selected groups using the rename feature of the *HEC-DSSVue* editor. The results of all four simulations were stored in the same DSS file by simply manually within the *HEC-DSSVue* editor adding the notations FM, D1, D2, or D3 to pathname part F. These types of operations are quick and convenient in *HEC-DSSVue*.

Separable *TABLES* output TOU files were created for the alternative simulations by multiple executions of *TABLES*. The sets of tables created with *TABLES* were combined and reformatted within Microsoft Excel and then copied into a Microsoft Word document.

Computer execution times for the four simulations executed on the same desktop computer are 0.0 second, 14 seconds, 39 seconds, and 46 seconds for simulations FM, D1, D2, and D4, respectively. Runtimes are modest for this small example WAM. However, for large WAMs, the differences in runtimes between daily and monthly simulations can be significant, perhaps many hours. Forecasting is a key factor in increasing computer execution times.

Reservoir Storage Contents

The storage capacities of the six reservoirs tabulated in Table 7.18 are the total cumulative volumes below their designated top of inactive, conservation, flood control, and

surcharge pool elevations, which assumes a flat water surface. The six reservoirs have active conservation storage capacities totaling 1,570,640 acre-feet. Whitney Reservoir has a 379,000 acre-feet inactive conservation pool that provides head for hydropower. The five gated operator-controlled flood control pools have storage capacities totaling 2,243,080 acre-feet. Possum Kingdom has a surcharge (*SIMD* uncontrolled flood pool) capacity of 95,300 acre-feet.

Table 7.18
Reservoir Storage Capacities

Reservoir	WAM Identifier <i>WS</i> field 2	Cumulative Storage Capacity at Top of Pool (acre-feet)			
		Inactive <i>WS</i> field 6	Conservation <i>WS</i> field 3	Flood Control <i>FR</i> field 9	Surcharge <i>FR</i> field 9
Possum Kingdom	PK	0	570,240		665,540
Whitney	Whit	379,000	627,100	2,000,000	
Waco	WacoL	0	192,100	726,400	
Belton	Belton	0	457,600	1,091,320	
Georgetown	George	0	37,100	130,800	
Granger	Grang	0	65,500	244,200	
Total Storage		379,000	1,949,640	4,192,720	665,540

In the model, the total storage capacity of the six reservoirs is 4,192,020 acre-feet. In the simulation computations, if a reservoir is full to capacity, outflow equals inflow. Thus, computed end-of-month or end-of-day storage contents cannot exceed storage capacities. The storage contents of each of the six reservoirs are set at its top of conservation pool capacity at the beginning of the simulation.

Water right WR-28 at control point Hemp, which is the single largest water supply diversion in the WAM, is supplied by stream flows supplemented by releases from Possum Kingdom, Belton, Georgetown, and Granger Reservoirs. Belton, Georgetown, and Granger Reservoirs also supply diversions at control point Camer. All six reservoirs have lakeside diversions. Whitney Reservoir is also operated to generate hydroelectric energy. Five reservoirs are operated as a system to reduce flood flows at downstream control points. Surcharge storage above the top of conservation pool at Possum Kingdom Reservoir is also modeled.

Monthly stream flow volumes from a daily simulation are summations of daily flow volumes. However, simulated end-of-day and end-of-month storage contents are quantities in units of acre-feet at an instant in time. The end-of-month storage contents for January 1940 is the same as the end-of-day storage contents for January 31, 1940. The 1940-2017 simulation period has 936 months and 28,490 days. For a particular daily simulation, the 936 end-of-month storage volumes are the same as the end-of-day storage volumes for the last day of each month.

Reservoir storage contents represent a meaningful measure of water availability. The storage frequency metrics for the four simulations tabulated in Tables 7.19 through 7.26 can be computed with *TABLES*, which uses Eq. 7.1, with 2FRE and 6FRE records shown in Table 7.15 but were actually computed with HEC-DSSVue, which uses the negligibly different Eq. 7.2.

The *HEC-DSSVue* plots of Figures 7.6 through 7.14 provide comparisons of the end-of-month storage contents from simulation FM and end-of-day storage contents of the six reservoirs resulting from simulations D1, D2, and D3. The legend for the figures is as follows.

.....	red dotted line	simulation FM end-of-month storage
-----	green dashed line	simulation D1 daily results D1d
- · - · - ·	black dashes and dots	simulation D2 daily results D2d
————	blue solid line	simulation D3 daily results D3d

The plots in Figures 7.6, 7.7, and 7.8 and the frequency metrics in Tables 7.19 and 7.20 are for the summations of the storage contents in each of the six reservoirs at the end of each of the 28,490 days or 936 months. Both *HEC-DSSVue* and *TABLES* provide convenient options for summing end-of-day or end-of-month storage volumes for any number of reservoirs. Figures 7.9 through 7.14 and frequency statistics Tables 7.21 through 7.26 are for individual reservoirs.

D3 is the only simulation that allows storage in the flood control pools as is evident from the plots. Significant differences between conservation storage levels for the FM versus daily simulations can be observed in the plots. During most periods of non-negligible differences, the FM storage contents tend to be higher than the daily simulations, but conversely during some periods at some reservoirs FM storage contents are lower. The differences between D1 and D2 simulated 1940-2017 daily storage volumes are relatively small.

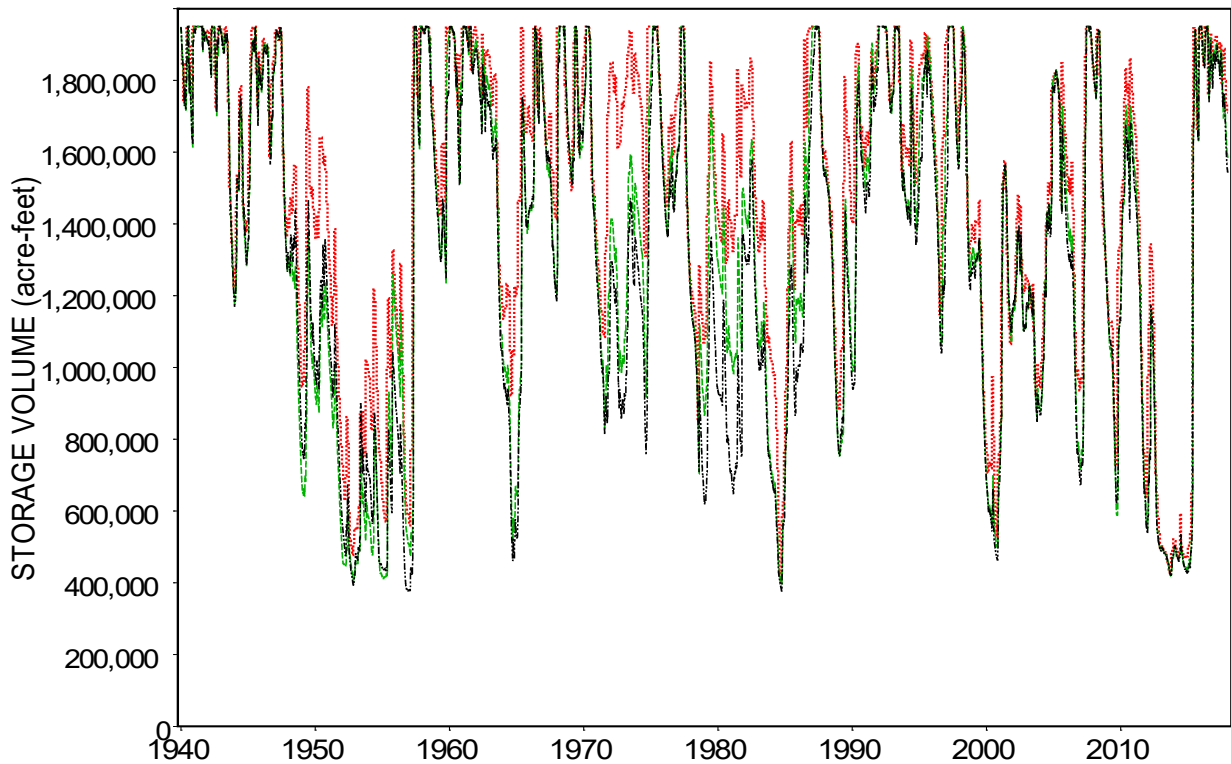


Figure 7.6 Summation of Storage Contents of the Six Reservoirs for Simulations FM, D1, D2 (FM red dotted line; D1 green dashed line; D2 black dashes and dots)

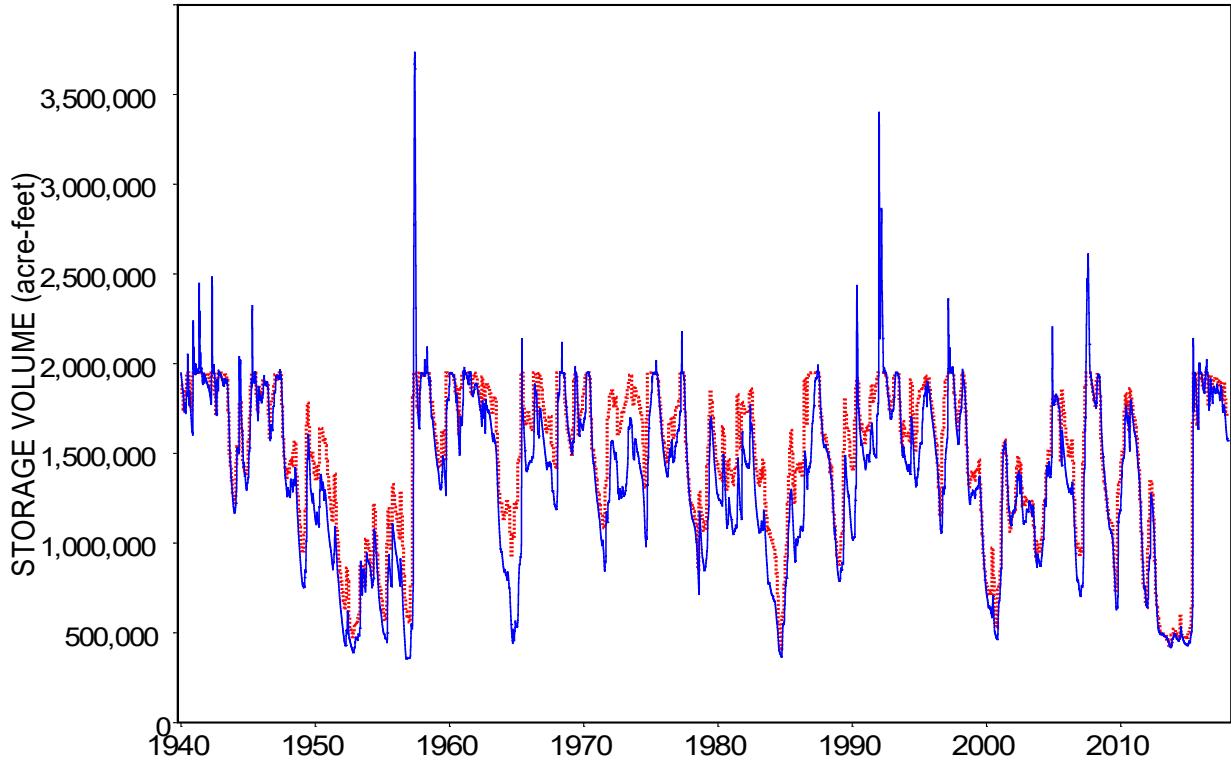


Figure 7.7 Summation of Storage Contents of the Six Reservoirs for Simulations FM and D3 (FM red dotted line; D3 blue solid line)

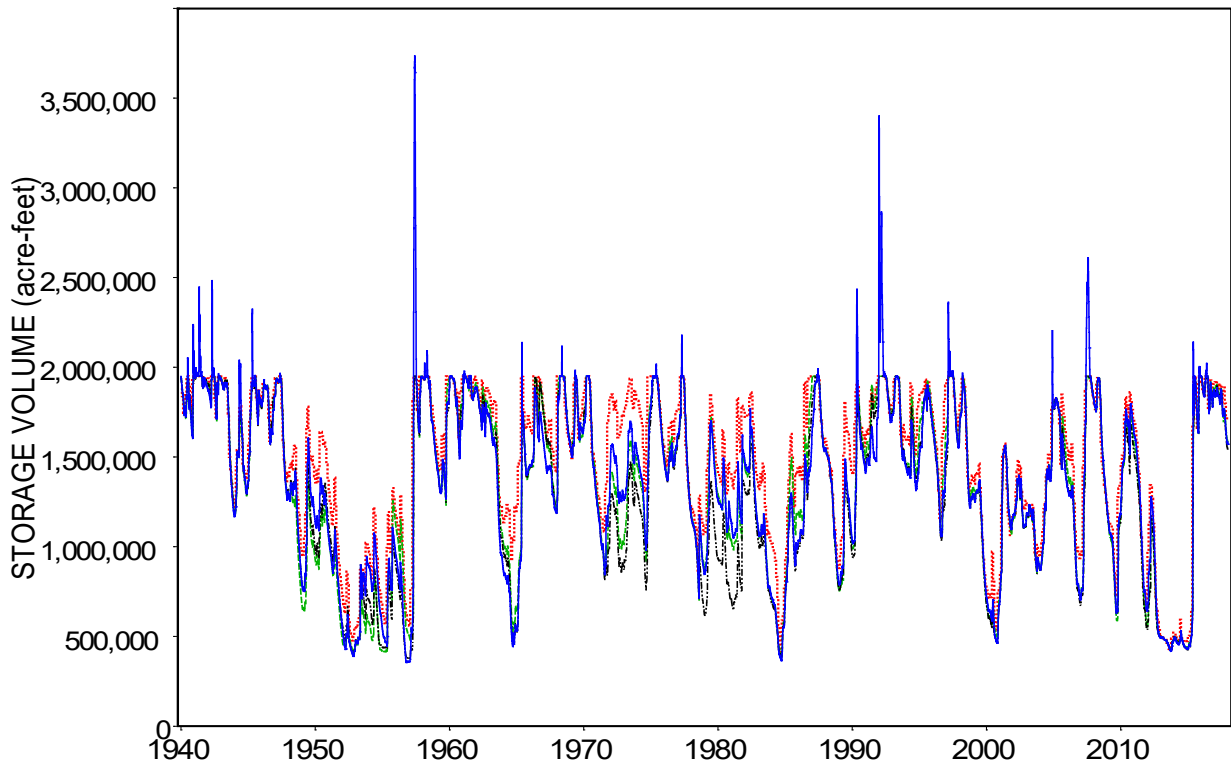


Figure 7.8 Summation of Storage Contents of the Six Reservoirs for the Four Simulations (FM red dotted line; D1 green dashed line; D2 black dashes and dots; D3 blue solid line)

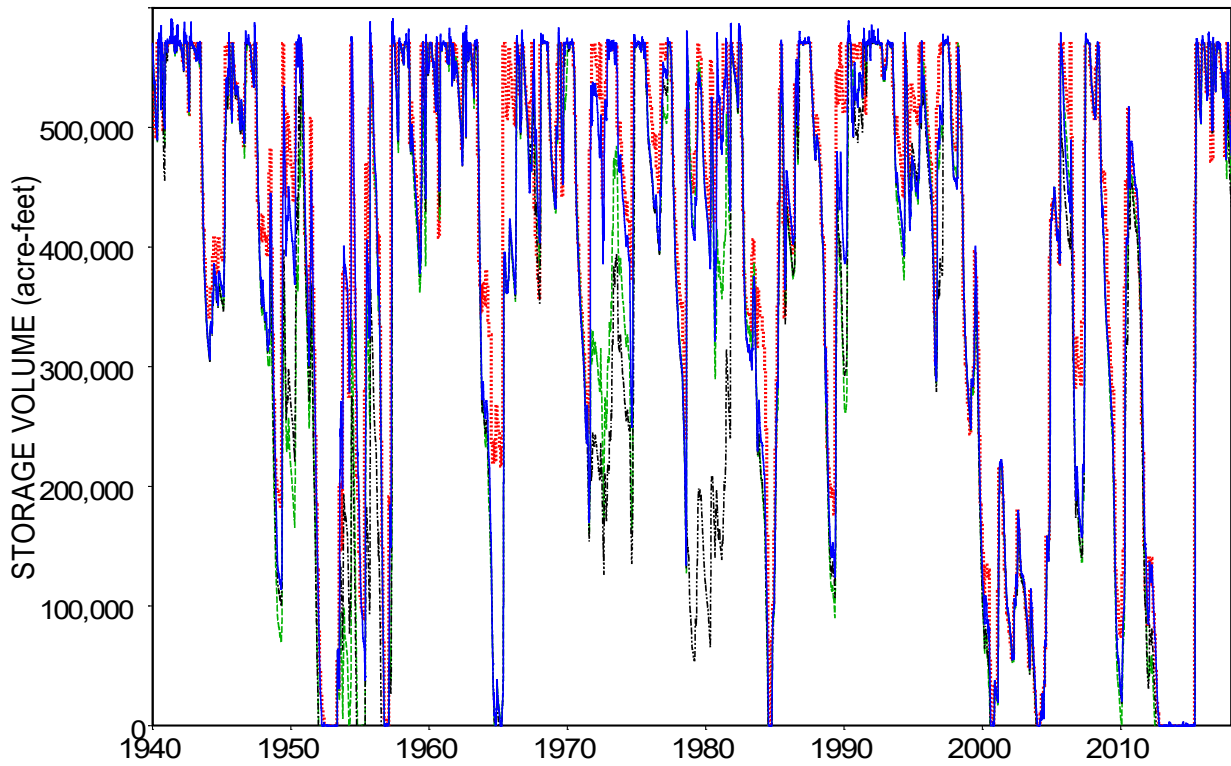


Figure 7.9 Storage Contents of Possum Kingdom Reservoir for the Four Simulations (FM red dotted line; D1 green dashed line; D2 black dashes and dots; D3 blue solid line)

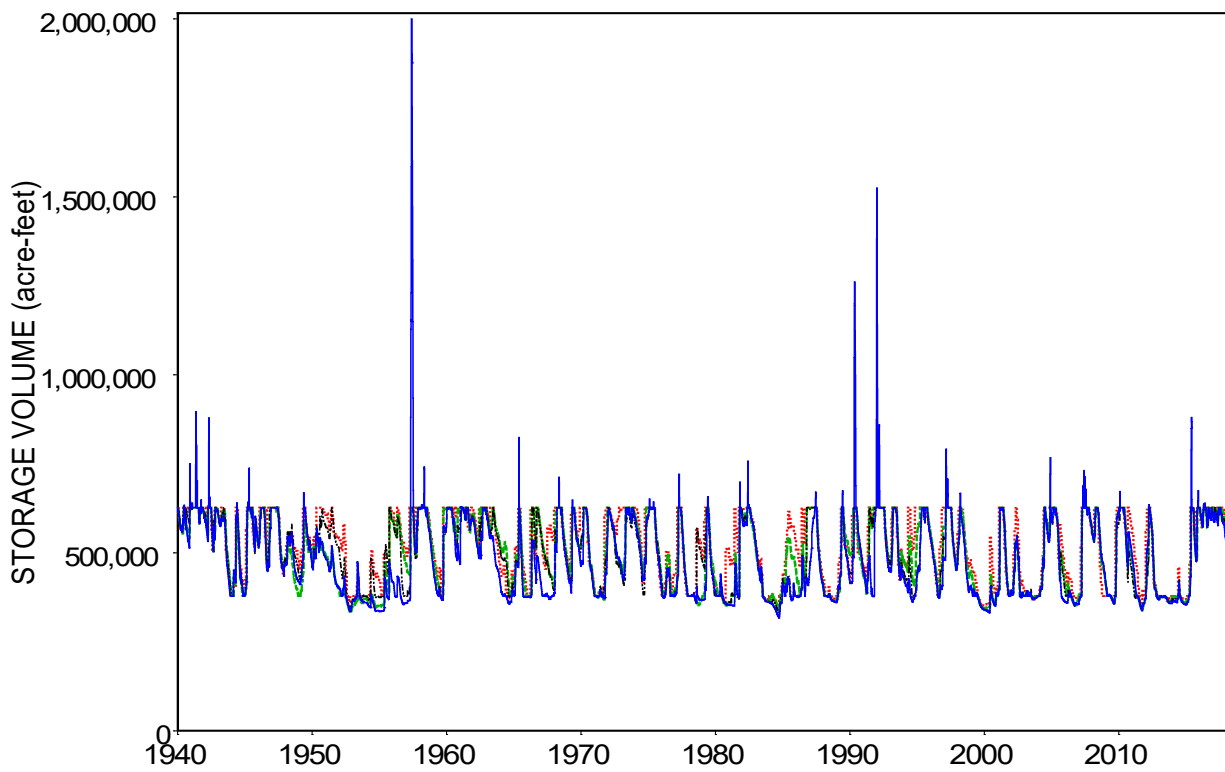


Figure 7.10 Storage Contents of Whitney Reservoir for the Four Simulations

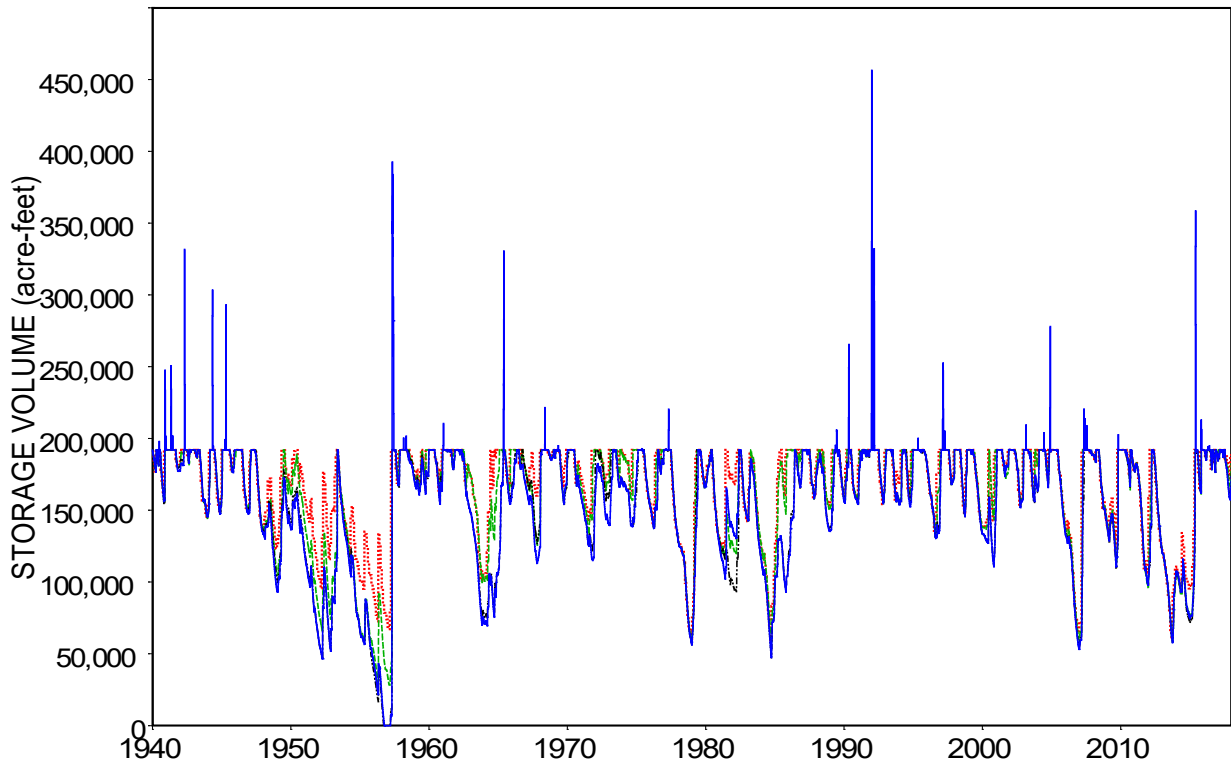


Figure 7.11 Storage Contents of Waco Reservoir for the Four Simulations

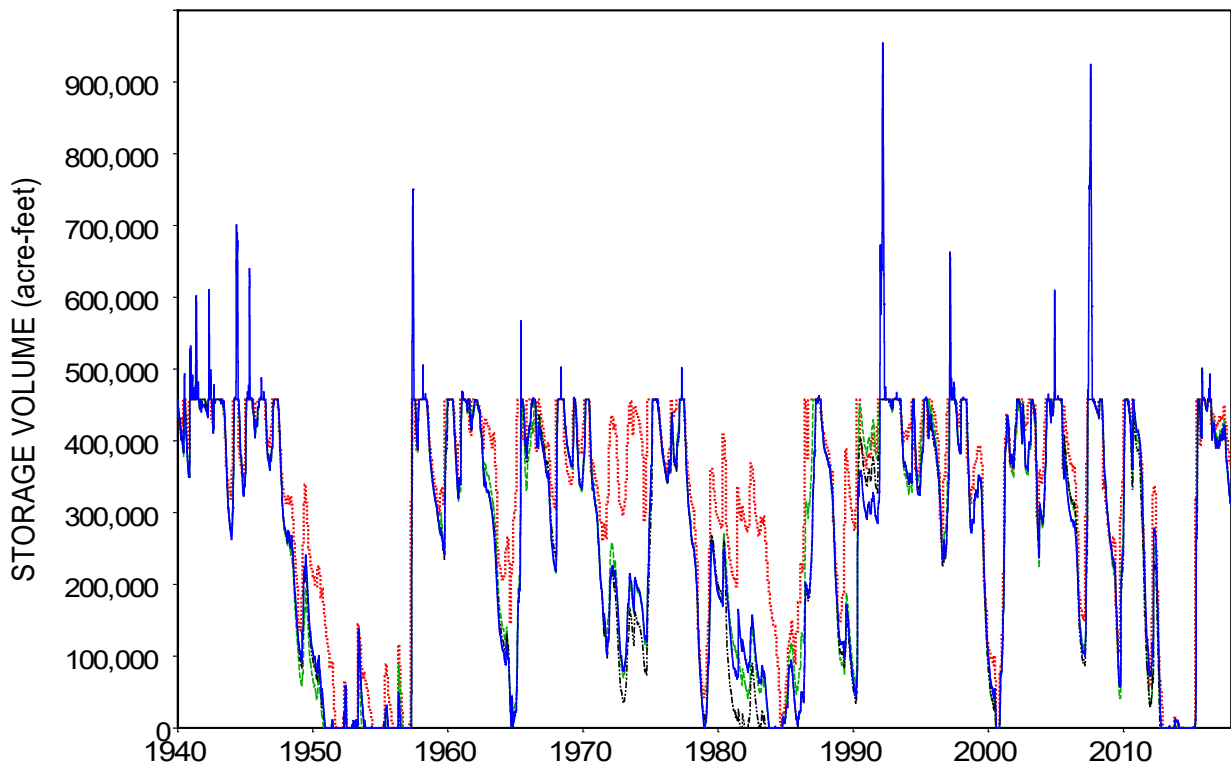


Figure 7.12 Storage Contents of Belton Reservoir for the Four Simulations (FM red dotted line; D1 green dashed line; D2 black dashes and dots; D3 blue solid line)

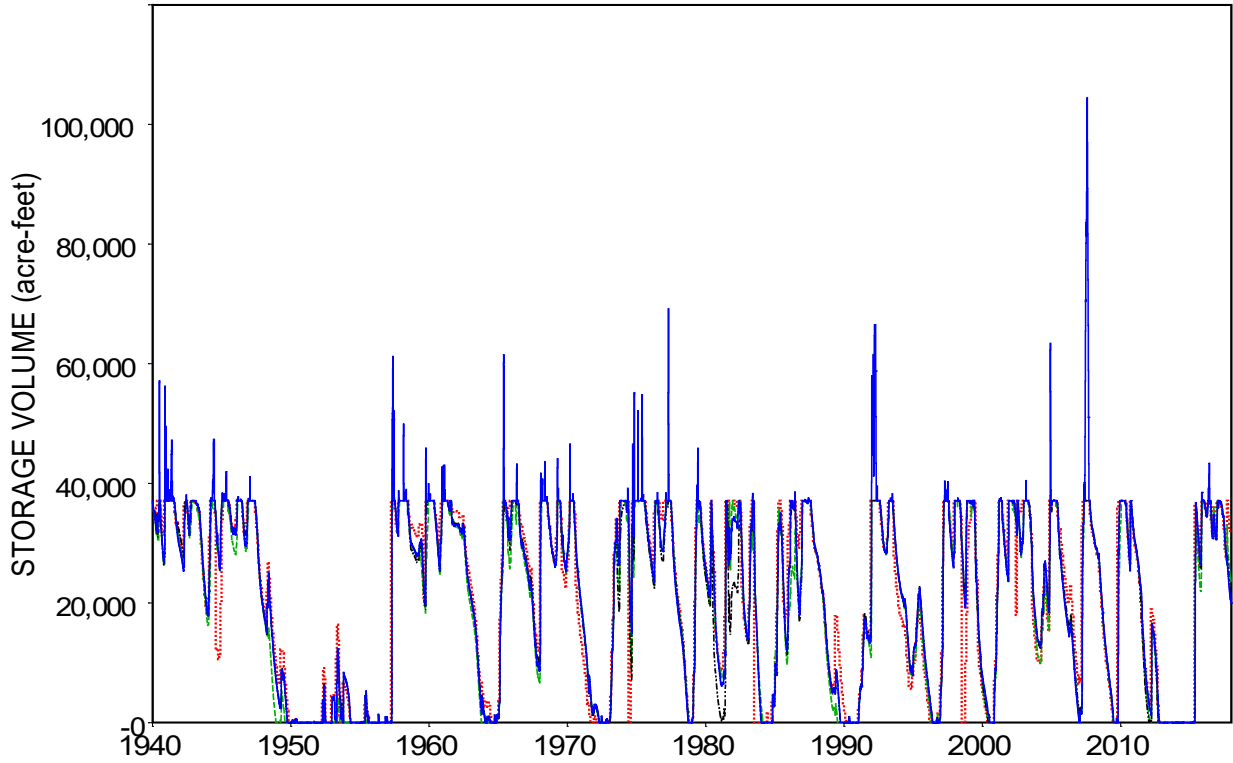


Figure 7.13 Storage Contents of Georgetown Reservoir for the Four Simulations (FM red dotted line; D1 green dashed line; D2 black dashes and dots; D3 blue solid line)

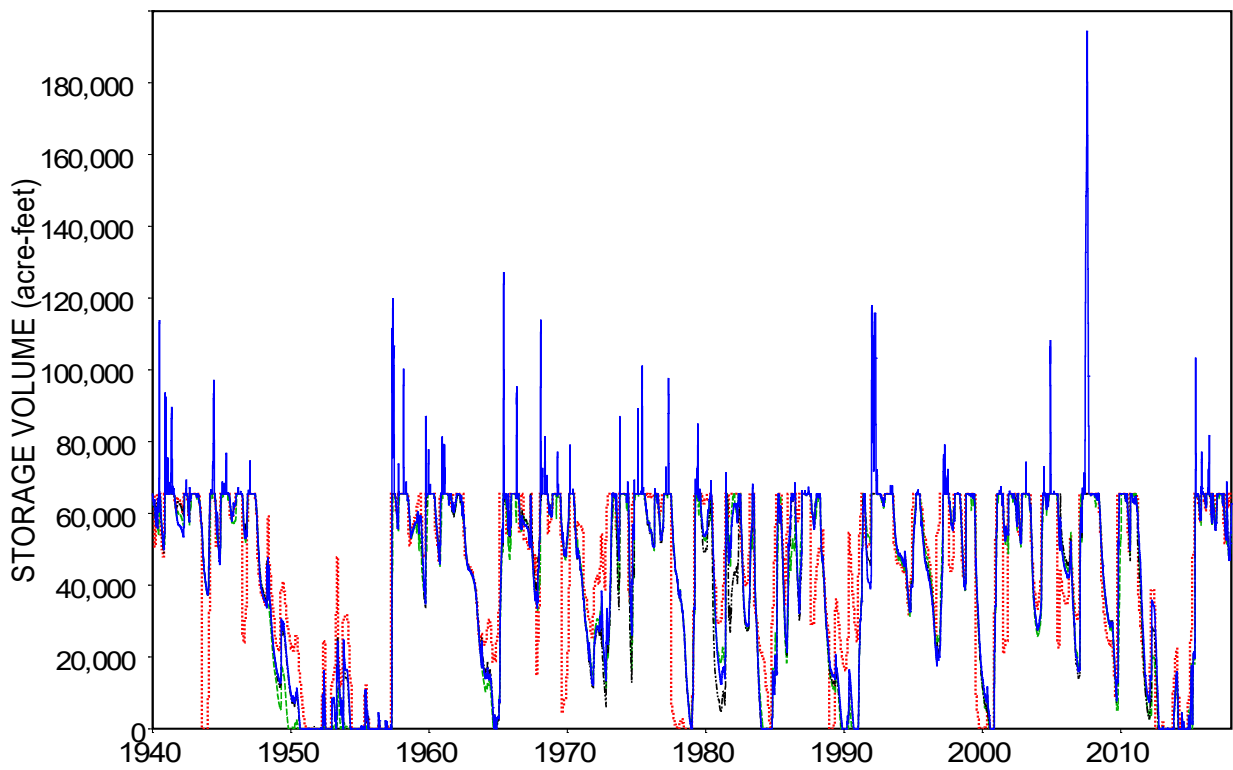


Figure 7.14 Storage Contents of Granger Reservoir for the Four Simulations

Both *HEC-DSSVue* and *TABLES* have features for computing frequency statistics. *HEC-DSSVue* and *TABLES* use Equations 7.1 and 7.2, respectively, which produce almost the same results with N of 936 months or 28,490 days. Both programs also include options for applying probability distribution functions. *TABLES* frequency tabulations begin with large exceedance frequencies as illustrated in Table 7.16. The statistics in the following tables were computed with *HEC-DSSVue* which produces frequency tabulations that begin small exceedance frequencies.

Table 7.19
Frequency Metrics for the Summation of Storage (acre-feet) in the Six Reservoirs

Simulation	FM	D1m	D2m	D3m	D1d	D2d	D3d
Mean	1,487,887	1,354,435	1,320,359	1,364,871	1,352,565	1,318,789	1,360,438
Stand Dev	418,842	461,821	468,881	470,650	462,448	469,304	465,667
Maximum	1,949,640	1,949,640	1,949,640	3,731,553	1,949,640	1,949,640	3,738,149
2%	1,949,640	1,949,640	1,949,640	2,107,945	1,949,640	1,949,640	1,998,939
5%	1,949,640	1,949,371	1,948,851	1,950,419	1,949,061	1,948,516	1,949,948
10%	1,947,896	1,926,897	1,916,920	1,923,810	1,926,352	1,919,627	1,919,743
15%	1,927,586	1,884,096	1,870,330	1,867,824	1,883,325	1,867,545	1,866,010
20%	1,889,346	1,824,151	1,817,645	1,808,032	1,827,672	1,814,253	1,805,137
30%	1,805,445	1,707,533	1,681,473	1,672,782	1,706,249	1,677,985	1,669,430
40%	1,711,796	1,561,088	1,514,614	1,525,693	1,554,447	1,514,404	1,525,550
50%	1,591,614	1,418,150	1,362,930	1,418,971	1,415,862	1,362,696	1,418,867
60%	1,453,595	1,266,952	1,224,578	1,279,954	1,271,461	1,222,607	1,284,048
70%	1,324,114	1,114,323	1,047,537	1,139,675	1,108,303	1,039,113	1,131,647
80%	1,126,757	932,028	854,673	922,606	921,307	852,037	915,688
85%	994,178	770,031	732,483	810,671	767,756	732,448	813,430
90%	830,381	604,501	598,327	656,376	603,421	607,196	658,764
95%	592,404	486,100	476,456	482,755	486,134	478,409	484,031
98%	489,274	445,376	435,838	442,964	442,919	435,943	438,922
99%	474,124	422,307	413,300	402,602	423,656	416,769	408,434
Minimum	403,113	396,722	376,944	354,516	396,722	376,944	354,470

Table 7.20
Storage Summation Frequency Metrics from Table 7.19 as a Percentage of FM Quantities

	FM	D1m	D2m	D3m	D1d	D2d	D3d
Mean	100.00%	91.03%	88.74%	91.73%	90.91%	88.64%	91.43%
Max	100.00%	100.00%	100.00%	191.40%	100.00%	100.00%	191.74%
2%	100.00%	100.00%	100.00%	108.12%	100.00%	100.00%	102.53%
10%	100.00%	100.00%	108.12%	100.00%	100.00%	102.53%	100.00%
30%	100.00%	94.58%	93.13%	92.65%	94.51%	92.94%	92.47%
50%	100.00%	89.10%	85.63%	89.15%	88.96%	85.62%	89.15%
70%	100.00%	84.16%	79.11%	86.07%	83.70%	78.48%	85.46%
90%	100.00%	72.80%	72.05%	79.05%	72.67%	73.12%	79.33%
99%	100.00%	89.07%	87.17%	84.91%	89.36%	87.90%	86.14%
Min	100.00%	98.41%	93.51%	87.94%	98.41%	93.51%	87.93%

Table 7.21
Frequency Metrics for Storage (acre-feet) in Possum Kingdom Reservoir

Simulation	FM	D1m	D2m	D3m	D1d	D2d	D3d
Mean	411,554	364,606	346,962	388,895	363,912	346,454	388,419
Stand Dev	180,319	192,917	195,467	186,031	192,958	195,348	185,843
Maximum	570,240	570,240	570,240	589,188	570,240	570,240	570,240
2%	570,240	570,240	570,240	576,092	570,240	570,240	574,758
5%	570,240	570,240	570,240	572,543	570,240	570,240	571,608
10%	570,240	570,037	570,035	570,673	570,175	570,131	570,498
15%	570,240	566,120	565,706	569,453	565,590	564,357	568,313
20%	570,240	553,285	550,257	561,035	552,911	550,601	559,629
30%	551,323	516,971	511,503	534,606	518,271	510,838	532,958
40%	517,559	472,356	453,353	495,784	472,225	455,125	495,963
50%	484,411	419,169	392,848	450,190	419,547	390,230	450,148
60%	437,183	362,349	316,249	402,150	361,329	316,271	404,011
70%	368,232	288,023	228,123	333,325	285,761	224,450	330,734
80%	245,834	152,373	132,662	204,809	149,606	132,083	200,772
85%	160,779	80,468	84,537	125,393	79,923	84,931	123,600
90%	88,686	23,014	26,066	61,469	24,181	26,696	59,661
95%	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7.22
Frequency Metrics for Storage (acre-feet) in Whitney Reservoir

Simulation	FM	D1m	D2m	D3m	D1d	D2d	D3d
Mean	521,585	496,162	493,259	483,447	495,885	493,015	481,665
Stand Dev	97,498	99,164	98,909	124,680	99,146	98,730	119,148
Maximum	627,100	627,100	627,100	2,000,000	627,100	627,100	2,000,000
2%	627,100	627,100	627,100	677,847	627,100	627,100	627,870
5%	627,100	627,100	627,100	627,100	627,100	627,100	627,100
10%	627,100	627,100	627,100	627,100	627,100	627,100	626,464
15%	627,100	627,000	622,576	617,262	626,164	622,186	615,657
20%	627,100	617,400	610,065	597,833	615,848	607,549	597,664
30%	622,098	579,932	578,616	554,863	580,380	578,064	554,923
40%	578,807	533,013	537,899	505,034	534,424	538,801	503,898
50%	539,507	494,758	487,944	460,227	493,649	486,309	459,260
60%	494,910	460,396	448,916	418,819	458,608	448,089	418,369
70%	453,858	410,588	402,639	383,937	409,591	401,960	384,005
80%	402,317	379,000	379,000	377,194	379,000	379,000	377,062
85%	379,000	378,282	377,294	371,019	378,400	377,358	371,544
90%	379,000	369,890	371,542	362,554	370,047	372,449	363,266
95%	372,679	358,724	360,911	354,616	359,217	361,784	355,474
98%	365,406	348,898	351,268	339,155	349,573	353,390	339,925
99%	358,037	345,258	339,879	335,492	345,576	341,188	336,192
Minimum	344,632	332,506	330,084	316,513	332,506	330,084	316,513

Table 7.25
Frequency Metrics for Storage (acre-feet) in Georgetown Reservoir

Simulation	FM	D1m	D2m	D3m	D1d	D2d	D3d
Mean	21,317	20,116	20,548	21,251	20,059	20,480	21,151
Stand Dev	14,579	14,344	14,238	15,068	14,358	14,245	14,984
Maximum	37,100	37,100	37,100	104,481	37,100	37,100	104,481
2%	37,100	37,100	37,100	42,684	37,100	37,100	40,627
5%	37,100	37,100	37,100	37,100	37,100	37,100	37,100
10%	37,100	37,100	37,100	37,100	37,100	37,100	37,100
15%	37,100	36,910	37,100	37,100	36,898	37,100	37,100
20%	37,100	35,659	36,372	36,595	35,582	36,259	36,421
30%	34,839	32,242	32,666	32,927	32,066	32,638	32,891
40%	31,486	28,453	28,834	29,211	28,523	28,703	29,297
50%	25,323	23,785	23,873	25,075	23,815	23,820	24,907
60%	17,449	16,747	17,392	17,838	16,403	17,397	17,696
70%	9,697	8,158	8,832	9,052	8,056	8,613	8,968
80%	2,318	262	1,738	2,243	213	1,402	1,910
85%	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7.26
Frequency Metrics for Storage (acre-feet) in Granger Reservoir

Simulation	FM	D1m	D2m	D3m	D1d	D2d	D3d
Mean	44,488	41,306	41,805	43,347	41,220	41,688	43,096
Stand Dev	23,455	24,519	24,153	25,571	25,718	24,216	25,391
Maximum	65,500	65,500	65,500	194,426	65,500	65,500	194,426
2%	65,500	65,500	65,500	81,939	65,500	65,500	75,258
5%	65,500	65,500	65,500	65,500	65,500	65,500	65,500
10%	65,500	65,500	65,500	65,500	65,500	65,500	65,500
15%	65,500	65,500	65,500	65,500	65,500	65,500	65,500
20%	65,500	65,500	65,500	65,500	65,500	65,500	65,500
30%	65,500	62,885	63,302	63,708	62,464	63,263	63,382
40%	63,268	57,189	57,897	57,906	57,270	58,006	57,971
50%	53,566	51,015	50,818	52,346	51,100	50,620	52,327
60%	43,212	41,141	40,981	41,810	41,071	40,952	41,581
70%	32,580	27,273	27,435	28,779	27,305	27,367	28,800
80%	22,314	11,368	13,006	14,837	11,165	12,550	14,600
85%	10,041	2,012	6,445	8,103	1,691	6,349	7,991
90%	353.0	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	0.0

For simulations FM, D1, and D2, Table 7.19 indicates that the maximum total storage volumes occurring during the 1940-2017 simulation is 1,949,640 acre-feet, which means that all six reservoirs are full to the top of conservation pool, as shown in Table 7.18. For simulation D3, Table 7.19 shows that the maximum summation of storage contents of the six reservoirs is

3,738,149 acre-feet which falls between the cumulative total storage capacities at the top of conservation and top of flood control pool of 1,949,640 and 4,192,720 acre-feet, respectively.

The four simulations are compared in Table 7.20 based on converting storage volumes in Table 7.19 to percentages of the storage metrics for simulation FM. For example, the mean storage contents for simulation results datasets D1m, D2m, d3m, D1d, D2d, and D3d are 91.03, 88.74, 91.73, 90.91, 88.64, and 91.43 of the mean of 1,487,887 acre-feet for simulation FM.

The storage frequency metrics in the columns labeled D1d, D2d, and D3d are computed from datasets composed of 28,490 end-of-day storage volumes. The frequency metrics in the columns labeled D1m, D2m, and D3m are computed from datasets composed of 936 end-of-month storage volumes, which are subsets of the D1d, D2d, and D3d datasets. End-of-month storage is the storage at the end of the last day of the month.

In the simulation model, refilling reservoir storage depends upon stream flow availability at the reservoir site and downstream control points. In a daily simulation, refilling in each day depends upon the volume of stream flow available in that day. The monthly simulation averages out stream flow availability over the month as illustrated by Figure 2.1 in Chapter 2. Thus, more stream flow may be available for filling storage in the monthly simulation.

Storage contents computed in the three daily *SIMD* simulations (D1, D2, D3) are significantly lower than the storage contents in the monthly *SIM* simulation (FM) during certain periods of the 1940-2017 hydrologic period-of-analysis as demonstrated by the preceding time series plots and frequency tables. However, the variations between the three daily simulations are relatively small compared to the difference between monthly and daily simulations. The greatest difference between simulations D1, D2, and D3 is the storage in the flood control pools, above the top of conservation pools, in simulation D3.

Water Supply Reliability

Volume reliability (R_v) for water supply diversion targets is defined as the percentage of the total target demand volume that is actually supplied during the simulation.

$$R_v = \frac{v}{V} (100\%) \quad (7.3)$$

The volume supplied (v) and target volume (V), typically in acre-feet, can be total or mean daily, monthly, annual, or entire simulation period volumes. With a daily simulation with daily results summed to monthly and annual totals, the computed value for R_v is the same for the daily simulation results and datasets of monthly and annual summations of diversions and shortages.

Period reliability is the percentage of the total number of periods during which 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 monthly *SIM* or daily *SIMD* simulation as:

$$R_p = \frac{n}{N} (100\%) \quad (7.4)$$

and shortages for simulations FM, D1, D2, and D3 are tabulated in Table 7.28. For any particular simulation, the volume reliability computed from daily versus monthly simulation results are exactly the same. Period reliabilities differ between daily versus monthly simulation results.

Table 7.30
Volume Reliabilities in Percent for Alternative Simulations

	FM	D1	D2	D3
PK	96.50	94.22	93.93	95.58
Whit	91.58	83.09	80.82	75.75
WacoL	100.0	100.0	99.55	99.57
WacoG	93.94	80.25	68.17	61.18
High	90.86	78.55	69.70	64.96
Belton	95.79	90.52	90.30	91.30
George	86.57	82.50	85.26	85.31
Grang	93.81	88.78	90.82	91.11
Camer	84.01	74.14	74.17	73.75
Bryan	95.46	86.49	87.02	84.21
Hemp	94.95	91.11	90.99	91.04
Total	93.86	88.74	88.23	88.09

Table 7.31
Period Reliabilities in Percent for Supplying 100% of Targets for Alternative Simulations

	FM	D1m	D2m	D3m	D1d	D2d	D3d
PK	94.87	91.13	91.03	93.06	92.25	92.40	94.43
Whit	91.88	78.42	74.68	69.02	83.45	80.64	75.74
WacoL	100.0	100.0	99.25	99.36	100.0	99.44	99.45
WacoG	96.69	54.81	28.85	24.25	86.21	70.30	67.36
High	95.51	55.88	35.90	32.26	86.50	78.02	73.62
Belton	94.34	87.07	86.86	88.35	89.33	89.21	90.30
George	83.44	77.99	81.20	81.20	81.19	84.48	84.59
Grang	91.24	85.36	87.71	87.93	87.83	90.07	90.36
Camer	80.24	32.26	28.74	27.09	65.67	63.30	62.63
Bryan	90.71	36.75	44.34	43.16	78.30	82.82	80.71
Hemp	85.58	38.25	49.04	48.61	75.86	79.58	78.77

Reliabilities for the monthly simulation are generally greater than for the daily simulations. However, period reliabilities based on daily simulation results tend to be higher than those based on monthly summations of daily simulation results. For example, consider the period reliability metric defined as the percentage of the time periods during which 100% of the diversion target is supplied. Hypothetically assume that shortages occur during exactly one day of each of the 936 months of the 1940-2017 simulation. Based on the daily simulation results:

$$R_P = [(28,490-936)/28,490]100\% = 96.71\%$$

With each of the 936 month having one day with a shortage, the months all have a shortage. Thus, based on applying Equation 7.4 to the monthly summations of the daily simulation results:

$$R_P = [(936-936)/936]100\% = 0.00\%$$

Period reliability metrics in the section of a 2REL table (Table 7.27) with the heading "*Percentage of Months*" is based on applying Equation 7.4 to the OUT file monthly FM simulation results. *TABLES* sums monthly diversion targets and shortages to annual volumes. Equation 7.3 is applied to develop the reliability metrics in the section of a 2REL table such as Table 7.27 with the heading "*Percentage of Years*." For example, Table 7.27 indicates that the total annual diversion volumes at control point PK during 75% of the 78 years of simulation FM equal or exceed 96.2% of annual diversion target of 254,800 acre-feet/year. The total monthly diversion volumes at control point PK during 75% of the 936 months of the simulation equal or exceed 95.1% of the monthly portions of annual target of 254,800 acre-feet/year

The period reliability quantities in the section of a 6REL tables (Tables 7.28 and 7.29) with the heading "*Percentage of Days*" are based on applying Equation 7.4 to the diversion targets and shortages read from the *SIMD* daily output SUB file for daily simulations D1, D2, and D3. For example, for simulation D3, diversions at PK equal or exceed 75% of the daily target during 94.6% of the 28,490 days. *TABLES* sums daily diversion target and shortage volumes to obtain monthly and annual volumes. Thus, the 6REL table includes period reliability sections for "*Percentage of Days*", "*Percentage of Months*", and "*Percentage of Years*".

Regulated and Unappropriated Stream Flow

A *SIMD* daily simulation transforms naturalized flow volumes in acre-feet at each control point in each day of the 28,490 days of the 1940-2017 period-of-analysis to regulated and unappropriated flow volumes in acre-feet. Daily volumes are summed to monthly volumes within *SIMD*. Both daily and aggregated monthly flows are included in the *SIMD* output files.

Daily regulated flows from the *SIMD* simulation results dataset D3d and monthly summations D3m of the daily regulated flows at Control point Hemp are plotted in Figures 7.15 and 7.16. Monthly regulated flows from *SIM* simulation FM at Control point Hemp are plotted in Figure 7.17. Monthly regulated flows versus exceedance frequency curves for simulation results datasets FM, D1m, D2m, and D3m are plotted in Figure 7.18. The four frequency curves are very similar to the extent of being almost indistinguishable from each other in the plots of Figure 7.18. The *SIMD* and *SIM* simulated regulated river flows in Figures 7.15, 7.16, 7.17, and 7.18 are monthly or daily volumes in acre-feet. Both daily and monthly flows are highly variable. The patterns of the daily versus monthly regulated flows in these plots exhibit both distinct similarities and distinct differences.

All of the time series plots in this report and the frequency plots of Figures 7.18 and 7.19 were created with *HEC-DSSVue*. The frequency plots were created using the feature accessed through the following path: *Tools/Math Functions/Statistics/Duration/Display/Plot*, which is different than the frequency plot options employed in Chapter 9. The time series plots are created through the normal *Display/Plot* menu options using the plot editor to refine the graphs.

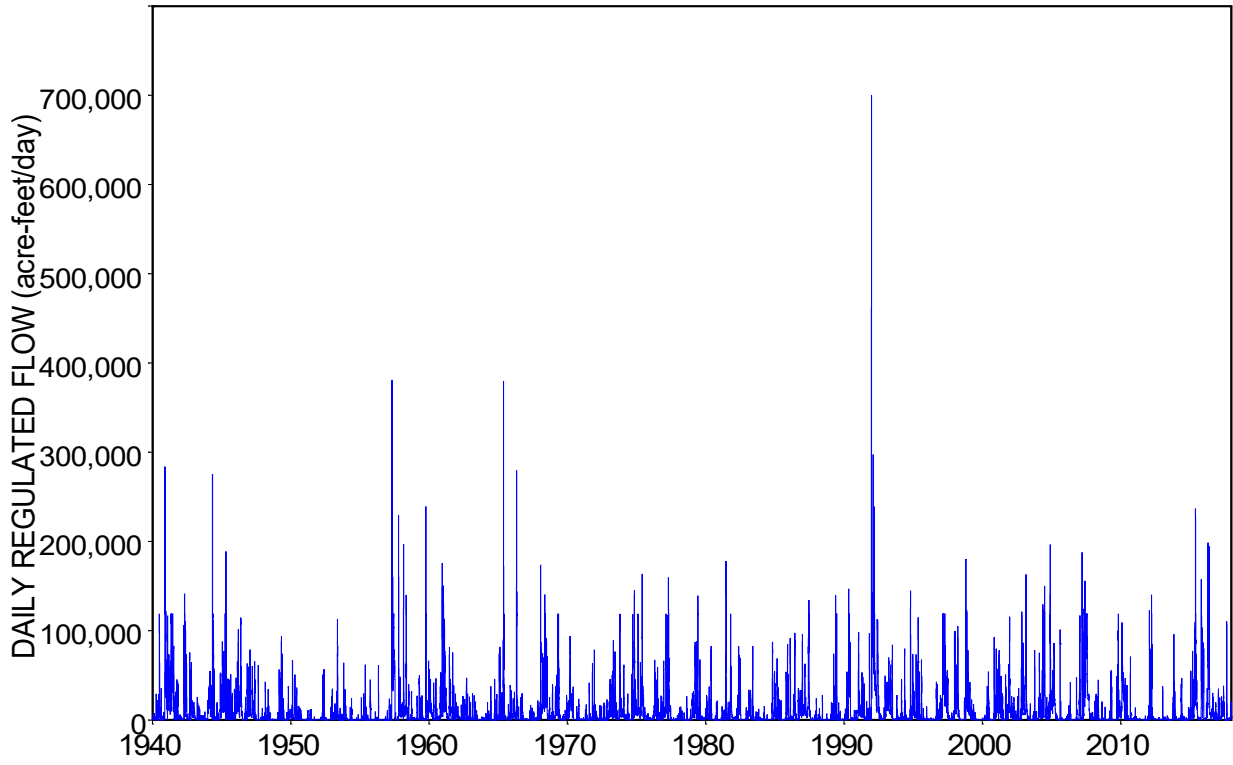


Figure 7.15 Simulation D3 Daily Regulated Flow (D3d) at Control Point Hemp in acre-feet/day

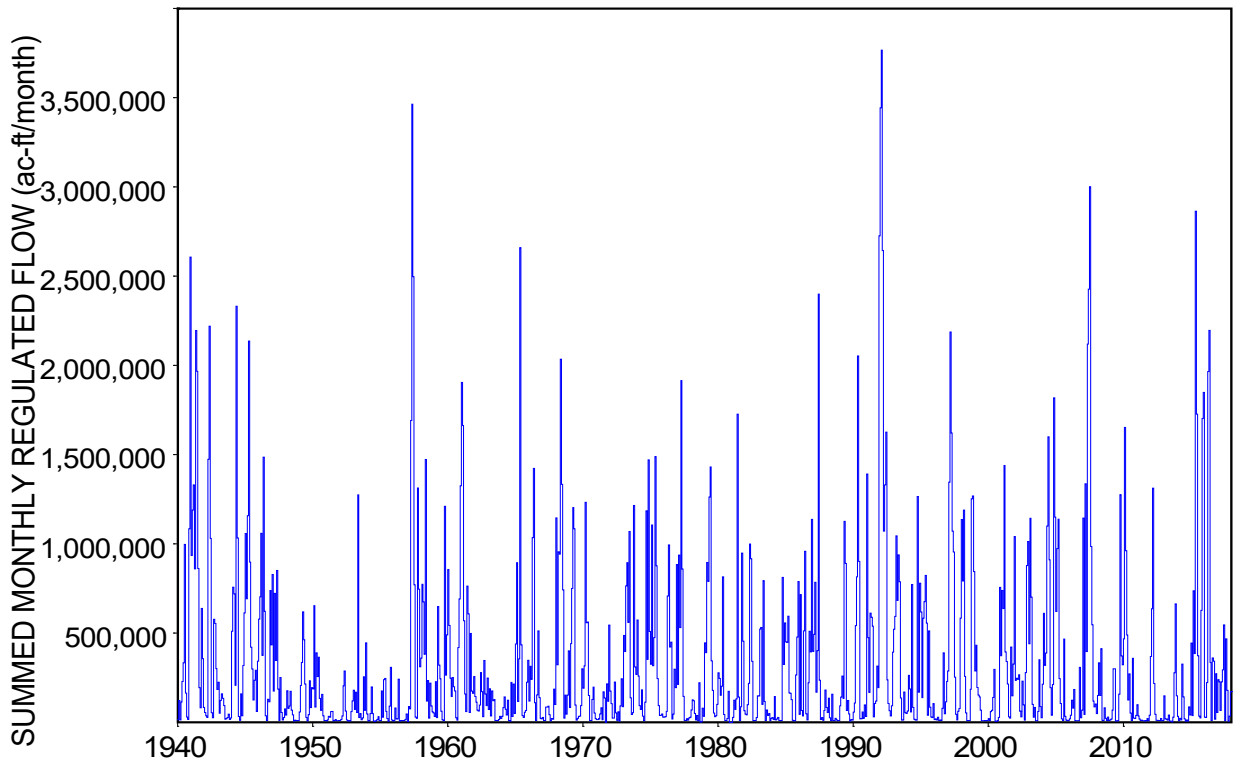


Figure 7.16 Simulation D3 Monthly Regulated Flow (D3m) at Hemp in acre-feet/month

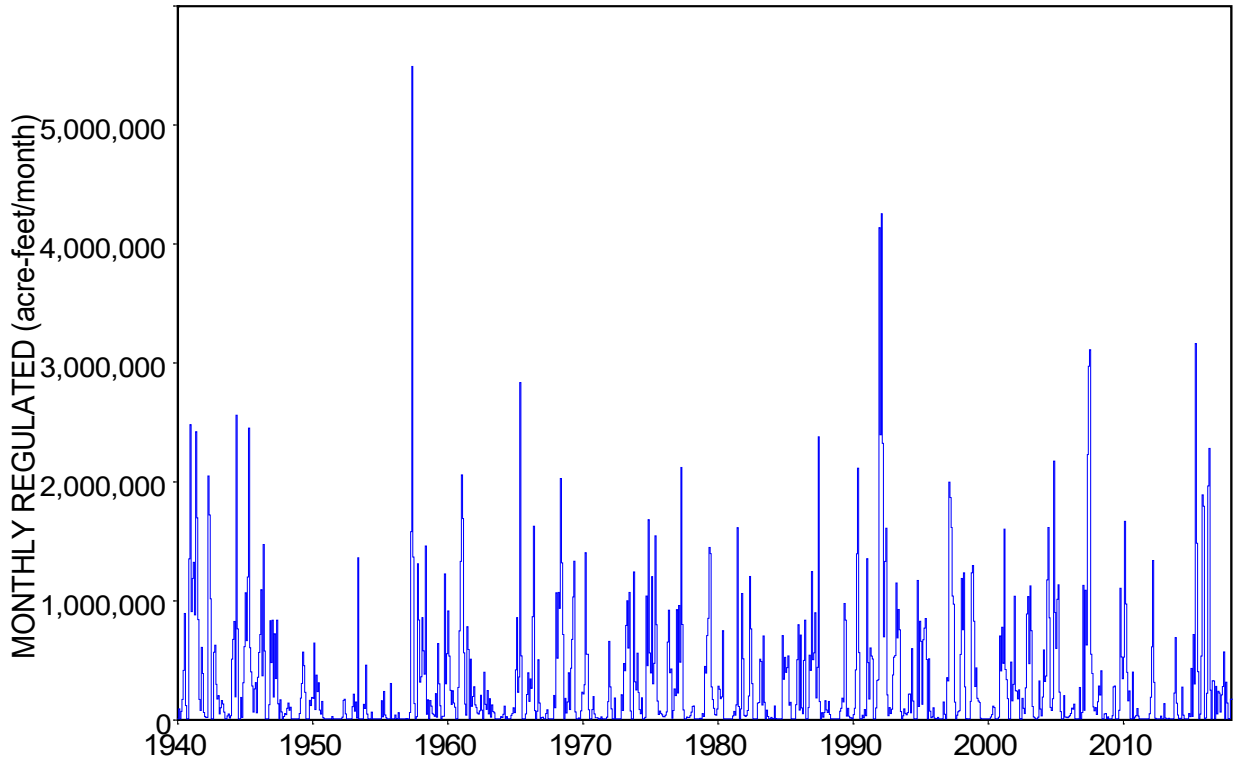


Figure 7.17 Simulation FM Monthly Regulated Flow at Control Point Hemp in acre-feet/month

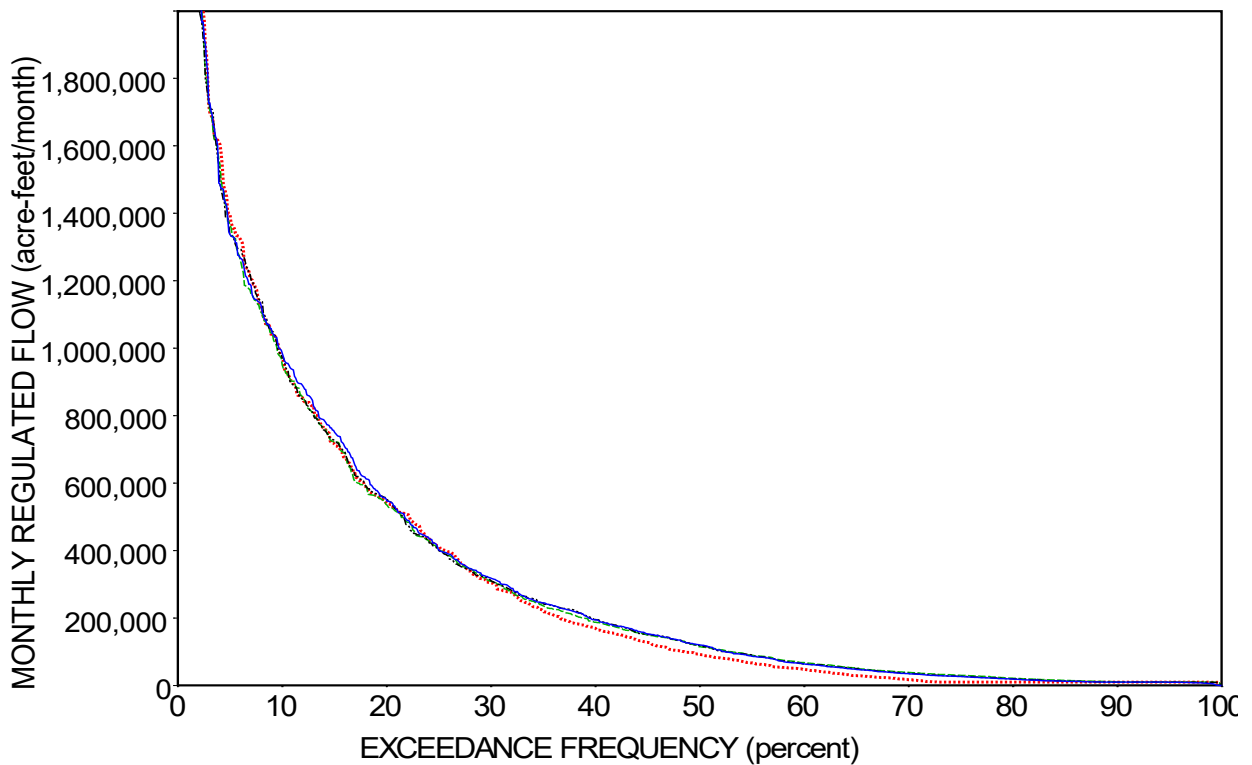


Figure 7.18 Control Point Hemp Regulated Flow Frequency Curves for FM (red dotted line), D1m (green dashed line), D2m (black dashes and dots), and D3m (blue solid line)

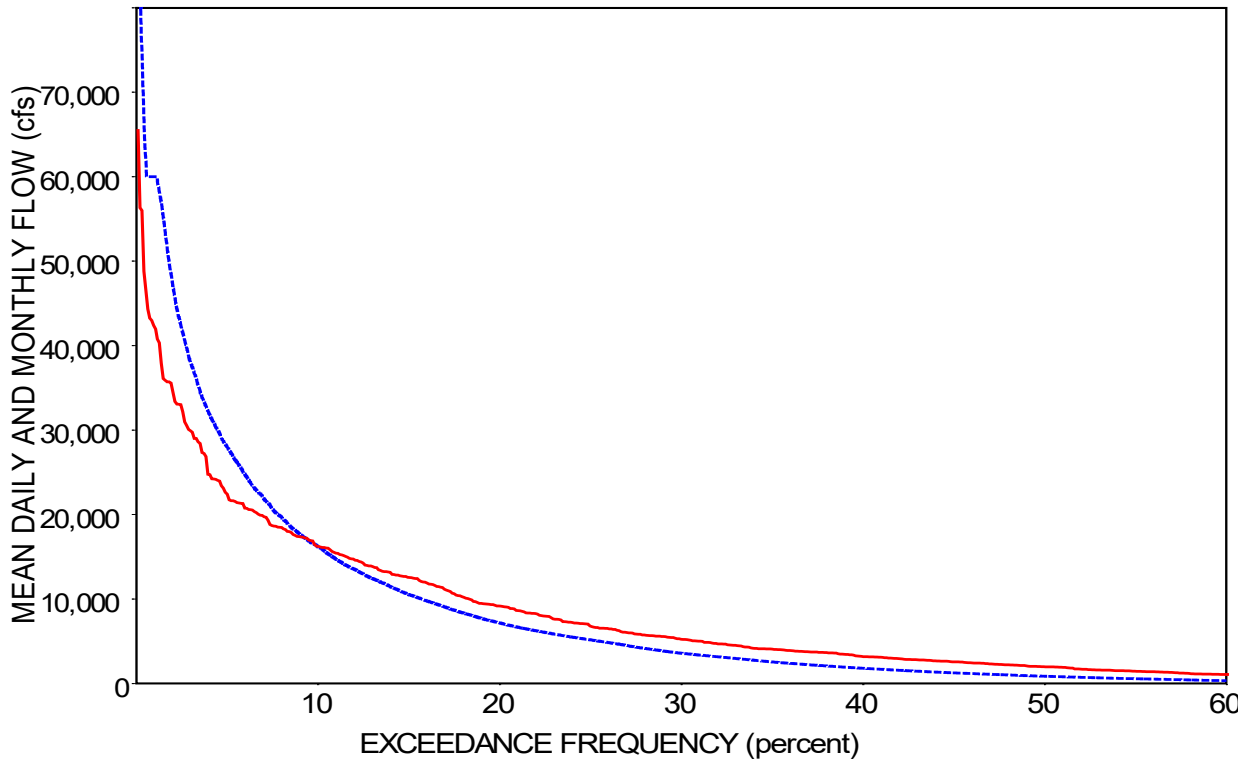


Figure 7.19 Simulation D3 Mean Daily (blue dashed line) and Mean Monthly (red solid line) Regulated Flow in cubic feet per second (cfs) at Control Point Hemp

Converting flows from daily volumes (or mean rates) to monthly volumes (or mean rates) greatly reduces variability as illustrated by the preceding plots and following frequency tables. The variability of instantaneous flow rates averaged over each month is much less than the variability of instantaneous flow rates averaged over each day of the period-of-analysis.

Frequency curves for mean daily and mean monthly regulated flow rates in cfs from simulation D3 (results datasets D3d and D3m) at control point Hemp are plotted in Figure 7.19. The 1940-2017 hydrologic period-of-analysis includes both months and days of zero regulated river flow. The peak mean daily flow rate during the simulation is 352,863 cfs on December 24, 1991. From Table 7.8, the maximum non-damaging flood limit at control point Hemp employed in operating the upstream flood control reservoirs is 60,000 cfs. The maximum mean monthly flow rate is 65,476 cfs during February 1992. The January 1940 through December 2017 average of both the daily and monthly flows is 5,574 cfs (Table 7.33). The standard deviations for the daily and monthly flows are 12,120 cfs and 8,567 cfs, respectively.

Frequency statistics for regulated and unappropriated flows at control points Camer and Hemp are tabulated in Tables 7.32, 7.33, 7.34, and 7.35. The regulated and unappropriated flows compared in these tables include monthly flows from the *SIM* monthly simulation (FM), and both the aggregated monthly flows (D1m, D2m, D3m) and daily flows (D1d, D2d, D3d) from the three daily *SIMD* simulations. The frequency metrics are expressed as mean daily and mean monthly flow rates in cfs in Tables 7.32, 7.33, 7.34, and 7.35 to facilitate comparative analyses of the monthly versus daily simulation results.

Table 7.32
 Statistical Frequency Metrics for Regulated Flows at Camer

	FM cfs	D1m cfs	D2m cfs	D3m cfs	D1d cfs	D2d cfs	D3d cfs
Mean	1,369	1,413	1,412	1,410	1,409	1,409	1,408
Std Dev	2,609	2,536	2,527	2,406	4,396	4,320	4,054
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99%	5.0	2.8	3.7	4.2	2.6	0.6	0.0
98%	5.0	5.4	5.0	7.0	5.0	4.8	4.8
95%	5.0	18.0	18.1	19.0	5.0	5.0	5.0
90%	5.0	55.7	68.4	55.0	5.0	5.0	5.0
80%	32.8	121.7	218.5	119.5	5.0	5.0	5.0
70%	106.5	209.9	333.8	205.1	35.1	26.4	27.4
60%	183.3	313.5	459.5	303.4	109.2	93.1	96.3
50%	333.2	447.7	635.8	439.2	208.8	204.1	203.3
40%	644.5	664.7	826.7	692.4	407.1	415.5	397.7
30%	1,030	1,106	1,204	1,113	744.7	761.0	734.3
20%	1,950	1,968	1,973	1,987	1,305	1,318	1,324
10%	3,759	3,775	3,888	3,935	3,265	3,337	3,497
Maximum	24,193	24,209	24,191	20,487	144,608	137,044	137,044

Table 7.33
 Statistical Frequency Metrics for Unappropriated Flows at Camer

	FM cfs	D1m cfs	D2m cfs	D3m cfs	D1d cfs	D2d cfs	D3d cfs
Mean	1,294	1,174	1,265	1,257	1,171	1,261	1,253
Std Dev	2,634	2,393	2,528	2,368	3,912	4,302	4,011
Minimum	0.0	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	0.0
98%	0.0	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	0.0
90%	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80%	0.0	3.1	1.4	0.7	0.0	0.0	0.0
70%	0.0	42.7	40.2	40.4	0.0	0.0	0.0
60%	64.0	104.4	108.8	113.3	0.0	0.0	0.0
50%	180.5	212.4	239.7	239.7	0.0	0.0	0.0
40%	439.2	408.0	455.4	470.9	118.4	95.9	104.9
30%	938.1	859.1	973.5	967.0	391.7	377.8	400.2
20%	1,945	1,580	1,810	1,815	1,055	1,118	1,142
10%	3,754	3,390	3,644	3,858	2,986	3,200	3,311
Maximum	24,206	23,647	24,204	20,483	128,580	137,039	137,039

Table 7.34
Statistical Frequency Metrics for Regulated Flows at Hemp

	FM cfs	D1m cfs	D2m cfs	D3m cfs	D1d cfs	D2d cfs	D3d cfs
Mean	5,456	5,560	5,576	5,574	5,547	5,562	5,574
Std Dev	9,150	8,896	8,845	8,567	12,706	12,836	12,120
Minimum	160.0	54.0	54.0	0.0	52.5	0.0	0.0
99%	165.8	165.8	155.9	93.7	165.8	41.4	0.0
98%	165.8	165.8	159.5	125.5	165.8	72.6	0.0
95%	165.8	165.8	164.5	158.9	165.8	165.2	49.1
90%	165.8	172.0	165.8	165.8	165.8	165.8	165.8
80%	165.8	357.1	328.3	318.7	165.8	165.8	165.8
70%	288.3	642.5	596.8	576.2	165.8	165.8	165.8
60%	801.1	1,112	1,064	1,067	315.7	324.8	333.3
50%	1,533	1,926	1,962	1,987	847.5	837.0	859.5
40%	2,788	3,106	3,250	3,204	1,831	1,752	1,803
30%	5,030	5,091	5,174	5,258	3,587	3,550	3,584
20%	9,010	8,937	9,179	9,173	7,066	7,051	7,180
10%	16,102	15,937	16,321	16,237	15,851	15,781	16,204
Maximum	89,324	85,741	73,975	65,476	382,211	376,413	352,863

Table 7.35
Statistical Frequency Metrics for Unappropriated Flows at Hemp

	FM cfs	D1m cfs	D2m cfs	D3m cfs	D1d cfs	D2d cfs	D3d cfs
Mean	5,290	5,395	5,413	5,417	5,384	5,402	5,407
Std Dev	9,150	8,896	8,844	8,563	12,707	12,834	12,118
Minimum	0.0	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	0.0
98%	0.0	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	0.0
90%	0.0	6.2	0.9	0.0	0.0	0.0	0.0
80%	0.0	191.3	163.5	160.4	0.0	0.0	0.0
70%	122.5	476.7	443.3	424.2	0.0	0.0	0.0
60%	635.4	946.4	906.3	916.1	150.4	159.1	167.6
50%	1,368	1,760	1,802	1,834	681.8	671.2	693.8
40%	2,623	2,940	3,084	3,038	1,665	1,586	1,637
30%	4,222	4,926	5,022	5,093	3,421	3,384	3,418
20%	8,848	8,771	9,013	9,008	6,900	6,885	7,014
10%	15,936	15,771	16,155	16,071	15,685	15,615	16,039
Maximum	89,158	85,576	73,815	65,316	382,046	376,247	352,697

In addition to differences in units, monthly frequency metrics are complicated a little by the non-uniform number of days in each of the 12 months of the year. *TABLES* input records that create time series tables include an input parameter CFS option that converts monthly or daily flow rates in acre-feet/month or acre-feet/day to mean monthly or daily rates in cubic feet/second (cfs). Converting to units of cfs provides consistent units for comparative analyses but does not mitigate the issue of computed volumes in months of different lengths (28, 29, 30, or 31 days)

Tables 7.32, 7.33, 7.34, and 7.35 and the naturalized flow frequency metrics in Table 7.16 presented earlier in this chapter were developed with *TABLES* with the default option on the 2FRE and 6FRE records activated to employ Equation 7.1 to perform the frequency analysis computations.

$$\text{Exceedance Frequency} = \frac{m}{N} (100\%) \quad (7.1)$$

The Tables 7.19 through 7.26 storage frequency tables and the flow frequency plots of Figures 7.18 and 7.19 were developed using the statistical analysis features of *HEC-DSSVue*, which employs Equation 7.2 instead Equation 7.1.

$$\text{Exceedance Frequency} = \frac{m}{(N + 1)} (100\%) \quad (7.2)$$

N is the either 936 months or 28,490 days in the 1940-2017 period-of-analysis and m is the rank. Equations 7.1 and 7.2 are essentially the same for large values of N such as 936 or 28,490.

TABLES and *HEC-DSSVue* frequency tabulations differ a little in format. *HEC-DSSVue* tabulations begin with the smallest exceedance frequencies and progress to larger frequencies while *TABLES* tabulation begin at the larger end of the exceedance frequency range. Both *TABLES* and *HEC-DSSVue* include options to employ probability distribution functions instead of Equations 7.1 and 7.2. Frequency analyses are addressed further in Chapter 9.

Comparative Analysis Summary

Computer simulation models are necessarily simplified approximations of the real world, but hopefully provide meaningful information regarding the real world systems being modeled. The monthly WAM and three versions of the daily WAM discussed in this chapter all reflect an assortment of approximations and complexities. All four models provide meaningful information. The monthly WAM completely ignores within-month variability. The three versions of the daily WAM address various aspects, but not all aspects, of within-month daily variability which may or may not be important or warranted for various modeling applications and situations. All versions of the WAM completely ignore within-day hourly or instantaneous variability which can be relevant for certain modeling applications and situations.

The primary objective of Chapter 7 is to explain and illustrate *SIMD* input files and records, simulation computations and results, *TABLES* and *HEC-DSSVue* capabilities for statistical analysis of simulation results, and various alternative modeling and analysis options. The comparative analyses of simulations FM, D1, D2, and D3 also provide an opportunity to explore the relative effects of the different daily *SIMD* modeling features on simulation results. The comparative analyses presented in this chapter result in the same general observations as the comparative analyses presented in the much more complex Brazos WAM Report [7].

Simulations FM, D1, D2, and D3 illustrate the different *SIMD* features activated in the process of converting a *SIM* monthly WAM to a *SIMD* daily WAM. 1940-2017 monthly and daily time series plots of reservoir storage and stream flow are compared in the figures. Tables 7.19 through 7.35 compare statistical frequency metrics for reservoir storage and stream flow and reliability metrics for water supply diversion demands for the four alternative simulations. In general, the differences in simulation results for simulations D1, D2, and D3 are relatively small compared to the differences between the monthly FM results and daily D1/D2/D3 results. The mean end-of-month storage contents for simulations D1, D2, and D3 are 91.0%, 88.7%, and 91.7% of the FM mean storage (Table 7.20). FM, D1, D2, and D3 total volume reliabilities are 93.86%, 88.74%, 88.23%, and 88.09% (Table 7.30). Corresponding mean unappropriated flows at the outlet are 5,290 cfs, 5,395 cfs, 5,413 cfs, and 5,417 cfs (Table 7.35).

D1 is a daily simulation without routing and forecasting and without flood control operations. Results vary significantly between simulations FM and D1. The extreme variability of naturalized stream flow is the primary factor responsible for the differences between the monthly versus daily simulations. In a daily simulation, refilling reservoir storage and meeting water supply demands in each day depends on the volume of stream flow available in that day. The monthly simulation averages out stream flow availability over the month, generally resulting in more stream flow being available for filling reservoir storage and supplying diversion targets as illustrated by Figure 2.1 in Chapter 2, while correspondingly reducing the unappropriated flows leaving the river system at the outlet.

Routing and forecasting are added in simulation D2. The time series plots and frequency and reliability statistics are similar for simulations D1 and D2. Routing parameters are very approximate and routing and forecasting are complex. However, in general, the simulation results for the example vary relatively little as a function of routing and forecasting.

The addition of flood control reservoir operations is the only difference between simulations D2 and D3. Of the four alternative simulations, D3 is the only simulation for which simulation results are affected by the large flood control pools above the top of conservation pools. Stream flow and reservoir storage contents vary greatly between D3 and the other three simulations during high flows but only minimally during non-flood periods.

Within-month daily variations of diversion targets can be modeled using options controlled by *DW* and *DO* records. Input data for these options are generally very approximate and/or difficult to obtain. These optional features are not employed in the example.

Flood control reservoir operations and high pulse environmental flow standards are the two aspects of water management that clearly can be modeled much more accurately with a daily WAM rather than monthly WAM. However, the accuracy of modeling water supply capabilities may or may not be improved by converting from a monthly to a daily WAM. A monthly WAM may be more accurate than a daily WAM in accessing water availability for water supply. The tables and figures presented in this chapter facilitate comparing results from simulations FM, D1, D2, and D3. However, conclusions regarding which of these simulations provide a more accurate measure of water supply reliability and reservoir and stream flow frequency statistics are difficult and vary depending on the purpose of the simulation study.

CHAPTER 8 ENVIRONMENTAL FLOW STANDARD EXAMPLES

The methods presented in Chapter 6 are illustrated in Chapter 8 by incorporating Senate Bill 3 (SB3) environmental flow standards (EFS) into the example water availability model (WAM) developed in Chapter 7. SB3 environmental flow standards for two sites in the Brazos River Basin are added in Chapter 8 to the *SIMD* input dataset of Chapter 7 using *IF*, *HC*, *ES*, and *PF* records. Later in the last section of this chapter, daily instream flow targets computed in a daily *SIMD* simulation are aggregated to monthly totals and incorporated in the input dataset for the monthly WAM employing the strategy described in the last section of Chapter 6.

The methods for modeling environment flow standards implemented by instream flow *IF*, hydrologic condition *HC*, environmental standard *ES*, pulse flow *PF*, and pulse flow options *PO* records are explained in Chapter 4 of the *Reference Manual* and Chapter 6 of this *Daily Manual*. The *IF*, *HC*, and *ES* records are applicable in both monthly *SIM* and daily *SIMD* simulations and are described in Chapter 3 of the *Users Manual*. *PF* and *PO* records are applicable only in a daily *SIMD* simulation and are described in Chapter 4 of the *Users Manual*.

Alternative Methods for Setting Instream Flow Targets

Water allocation routines in *SIM* and *SIMD* are based on user-assigned priorities for all *WR* and *IF* record water rights. As each water right is considered in turn in the priority sequence, water supply diversion targets, hydroelectric energy generation targets, reservoir storage refilling targets, and instream flow targets are determined and water is allocated to meet the targets subject to water availability. An instream flow *IF* record water right sets a target minimum regulated flow rate at a control point location for each monthly or daily simulation time step. The objective of an *IF* record right is to maintain regulated flows equal to or greater than computed instream flow targets, subject to water availability. Upstream junior *WR* record water rights are curtailed as necessary to achieve downstream senior *IF* record minimum regulated flow targets.

Various *SIM* and *SIMD* options can be employed to set instream flow targets at a control point at a particular stage of the water right priority sequence for a particular month of a *SIM* monthly simulation or day of a *SIMD* daily simulation. Upon establishing an instream flow target, the target is employed in the same manner regardless of the options used to determine the target. This chapter focuses on the specification of *IF* record minimum regulated flow targets using *HC*, *ES*, *PF*, and *PO* records.

Flexible *SIM/SIMD* capabilities for computing *IF* record instream flow targets and *WR* record diversion targets employ various combinations of options provided by *IF* and *WR* records and auxiliary *UC*, *TO*, *SO*, *TS*, *WS*, *BU*, *PX*, *DI*, *IP*, *IS*, *IM*, *CV*, *FS*, *HC*, and *ES* records. These options are applicable in both *SIM* monthly and *SIMD* daily simulations and are described in *Reference Manual* Chapter 4 and *Users Manual* Chapter 3. *DW*, *DO*, *PF*, and *PO* records covered in Chapter 4 of the *Users Manual* and Chapters 2, 6, and 8 of this *Daily Manual* provide additional *IF* and *WR* record target-setting options applicable in only a daily *SIMD* simulation.

This chapter focuses on specifying rules for determining *IF* record minimum regulated flow targets in the format of SB3 environmental flow standards. *HC*, *ES*, *PF*, and *PO* records are

designed to replicate the structure and metrics employed in SB3 environmental flow standards. The *IF* record instream flow targets computed based on *HC*, *ES*, *PF*, and *PO* records specifications are employed in the simulation in the same manner as *IF* record targets computed based on any of the other options noted in the preceding paragraph. The environmental flow standard modeling strategy is activated by entering a negative value in *IF* record field 3 instead of an annual target amount. *HC*, *ES*, *PF*, and/or *PO* records follow the *IF* record.

Instream Flow Rights in the Original Fundamentals Manual Example

A daily version of the monthly WAM presented in the *Fundamentals Manual* is developed in the preceding Chapter 7 of this *Daily Manual*. The river/reservoir system shown in Figure 7.1 is modeled by the *SIMD* DAT file replicated in Table 7.3. Instream flow rights IF-1 and IF-2 in the *Fundamentals Manual* example illustrate the simplest of target setting options. However, instream flow targets computed using any other options, involving any level of complexity, are employed in the same manner in the simulation.

Both the monthly and daily versions of the example WAM DAT file in Table 7.3 contain two simple instream flow rights which are completely defined by the following two *IF* records.

IF Camer	3600.	NDAYS	0	IF-1
IF Hemp	120000.	NDAYS	0	IF-2

Instream flow water rights IF-1 and IF-2 set instream flow targets at control points Camer and Hemp for each month of a monthly *SIM* simulation or each day of a daily *SIMD* simulation. Annual targets of 3,600 and 120,000 are-feet are uniformly distributed over months and days.

The NDAYS option specified in *IF* record field 4 distributes the annual target to the 12 months of the year in proportion to the number of days in each month. The NDAYS option assigns 28 days to February in all years, including leap years. The alternative LDAYS option is identical to the NDAYS option except that February is assigned 29 days in leap years.

With the default ND(wr) option (blank *JU* field 9 and no *DW* record), monthly targets are uniformly distributed to daily. Thus, the annual targets of 3,600 and 120,000 acre-feet are uniformly distributed over the 365 days of the year or 366 days of a leap year in a *SIMD* daily simulation. The daily instream flow targets are 9.863014 acre-feet/day (9.836066 acre-feet/day in leap years) and 328.7671 acre-feet/day (327.8689 acre-feet/day in leap years) for instream flow rights IF-1 and IF-2, respectively.

The priority of zero assigned to both *IF* record rights IF-1 and IF-2 make them the most senior water rights in the DAT file of Table 7.3. All of the other water rights have larger priority numbers in the example. In general, *IF* record rights can be assigned any priority in the model.

No *WS* records follow the *IF* records. Thus, no releases from reservoir storage are made to maintain the instream flow targets. However, all reservoirs located upstream must pass inflows as necessary to maintain the senior downstream instream flow targets. Passing inflows means making releases each day not exceeding inflows during the day. Likewise, upstream junior water right diversions are curtailed as necessary to protect the instream flow targets at control points Camer and Hemp in the *SIMD* simulation.

Comparison of Basics of Alternative Strategies for Setting Minimum Instream Flow Limits

As discussed on the preceding page, the *SIMD* DAT file of Table 7.3 includes the following two *IF* record rights which result in minimum instream flow limit targets of 9.863014 acre-feet/day (9.836066 ac-ft/day in leap years) and 328.7671 acre-feet/day (327.8689 ac-ft/day in leap years) at control points Camer and Hemp, respectively.

IF Camer	3600.	NDAYS		IF-1
IF Hemp	120000.	NDAYS		IF-2

Alternatively, these instream flow targets could also be modeled with *ES* records as follows. Either of these two alternative modeling approaches yield the same results. The two alternative strategies for modeling IF-1 and IF-2 are compared to help explain the *ES* record.

IF Camer	-9													IF-1
ES	4.9726	4.9726	4.9726	4.9726	4.9726	4.9726	4.9726	4.9726	4.9726	4.9726	4.9726	4.9726	4.9726	
IF Hemp	-9													IF-2
ES	165.753	165.753	165.753	165.753	165.753	165.753	165.753	165.753	165.753	165.753	165.753	165.753	165.753	

The -9 in *IF* record field 3 activates the *HC/ES/PF* record modeling strategy. With *ES* record field 2 blank, hydrologic conditions are not used and a *HC* record is not needed. The minimum instream flow limits of 4.9726 cfs and 165.753 cfs entered on the *ES* records are converted to 9.8630 and 328.77 acre-feet/day within the *SIMD* simulation computations.

With 365 days in a year, 4.9726 cfs and 165.753 cfs are equivalent to 3,600 and 120,000 acre-feet/year. For leap years with 366 days, 4.9726 and 165.753 cfs are equivalent to 3,609 and 120,329 acre-feet/year. Conversion factors relevant to this discussion include 86,400 seconds/day and 43,560 cubic feet per acre-foot.

Combining of Multiple Instream Flow Targets at the Same Control Point

The remainder of this chapter after this introductory overview focuses on adding two new *IF* record instream flow rights to the *Fundamentals Manual* water availability model (WAM). The two *IF* record rights in the original example WAM presented in the preceding Chapter 7 are removed. The two new *IF* record water rights modeling SB3 environmental flow standards are the only *IF* record rights included in the example discussed in the remainder of this chapter. However, capabilities for combining target setting features in a simulation are noted as follows.

The simulation model allows any number of *IF* record rights to be assigned to any control point. The selection parameter IFM(IF,2) in *IF* record field 7 controls the combining of two targets computed by different *IF* record rights at the same control point. The default is for the target computed by the more junior *IF* record right to replace the preceding more senior target.

Each of the two *IF* record rights incorporated in the example presented later in this chapter consists of a *HC* record, set of *ES* records, and set of *PF* records. Each *IF* record right could be divided into two or more rights. For example, the set of *ES* records and set of *PF* records could be treated as two separate *IF* record rights which would result in separate water right output records. The simulation results would not be affected, other than the output files would include separate output for each of the *IF* water rights which could facilitate analyses.

SB3 Environmental Flow Standards

Senate Bill 3 (SB3) environmental flow standards (EFS) are discussed in Chapter 4 of the *Reference Manual*. SB3 EFS for seven groups of river systems that have been adopted to date can be found at the following TCEQ website.

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

Summary information regarding these EFS are presented in Tables 4.3 and 4.4 of the *Reference Manual*. Flow standards have been established at 19 USGS gage sites on the Brazos River and its tributaries. Environmental flow standards at two of these sites are adopted here for this example.

The remainder of this chapter focuses on an illustrative example consisting of incorporating SB3 instream flow standards at control points Camer and Hemp (Figure 7.1) into the example of the preceding Chapter 7. USGS gage sites adopted as control points in the example presented in Chapter 7 are listed in Table 7.1. Control point Camer is the gage on the Little River near Cameron. Control point Hemp is the gage on the Brazos River near Hempstead.

SB3 EFS at control points Camer and Hemp are summarized in Tables 8.1 and 8.2 [6, 16]. The standards include subsistence, base, and high flow pulse components as defined in Chapter 4 of the *Reference Manual* and Chapter 6 of this *Daily Manual*.

Table 8.1
Environmental Flow Standards (EFS) at the USGS Gage on the Little River near Cameron

1	2	3	4	5	6	7
Season	Subsistence Flow	Hydrologic Condition	Base Flow	Dry Condition Seasonal Pulse	Average Cond. Seasonal Pulse	Wet Condition Seasonal Pulse
Winter	32 cfs -0- -0-	Dry Average Wet	110 cfs 190 cfs 460 cfs	1 per season Trigger 1,080 cfs Volume 6,680 af Duration 8 days	3 per season Trigger 1,080 cfs Volume 6,680 af Duration 8 days	2 per season Trigger 2,140 cfs Volume 14,900 af Duration 10 days
Spring	32 cfs -0- -0-	Dry Average Wet	140 cfs 310 cfs 760 cfs	1 per season Trigger 3,200 cfs Volume 23,900 af Duration 12 days	3 per season Trigger 3,200 cfs Volume 23,900 af Duration 12 days	2 per season Trigger 4,790 cfs Volume 38,400 af Duration 14 days
Summer	32 cfs -0- -0-	Dry Average Wet	97 cfs 160 cfs 330 cfs	1 per season Trigger 560 cfs Volume 2,860 af Duration 6 days	3 per season Trigger 560 cfs Volume 2,860 af Duration 6 days	2 per season Trigger 990 cfs Volume 5,550 af Duration 8 days

In general, all components can vary seasonally and with hydrologic condition. However, for the Brazos River Basin SB3 environmental flow standards (EFS), the subsistence flows are constant for all seasons and are applied only for dry conditions. The base flow limits are functions of both season and hydrologic condition. The pulse flow specifications also vary

between seasons and hydrologic conditions. Seasons and hydrologic conditions are listed in columns 1 and 3 of Tables 8.1 and 8.2. Subsistence and base flow limits in cfs are tabulated in columns 2 and 4. Pulse flow specifications are shown in columns 5, 6, and 7.

Table 8.2
Environmental Flow Standards (EFS) at the USGS Gage on the Brazos River near Hempstead

1	2	3	4	5	6	7
Season	Subsistence Flow	Hydrologic Condition	Base Flow	Dry Condition Seasonal Pulse	Average Cond. Seasonal Pulse	Wet Condition Seasonal Pulse
Winter	510 cfs -0- -0-	Dry Average Wet	920 cfs 1,440 cfs 2,890 cfs	1 per season Trigger 5,720 cfs Volume 49,800 af Duration 10 days	3 per season Trigger 5,720 cfs Volume 49,800 af Duration 10 days	2 per season Trigger 11,200 cfs Vol. 125,000 af Duration 15 days
Spring	510 cfs -0- -0-	Dry Average Wet	1,130 cfs 1,900 cfs 3,440 cfs	1 per season Trigger 8,530 cfs Volume 85,000 af Duration 13 days	3 per season Trigger 8,530 cfs Volume 85,000 af Duration 13 days	2 per season Trigger 16,800 cfs Vol. 219,000 af Duration 19 days
Summer	510 cfs -0- -0-	Dry Average Wet	950 cfs 1,330 cfs 2,050 cfs	1 per season Trigger 2,620 cfs Volume 17,000 af Duration 7 days	3 per season Trigger 2,620 cfs Volume 17,000 af Duration 7 days	2 per season Trigger 5,090 cfs Vol. 40,900 af Duration 9 days

Seasons and Hydrologic Conditions

Seasons are defined in the Brazos River Basin SB3 EFS as follows: Winter (November through February), Spring (March through June), and Summer (July through October).

Regional values of the Palmer hydrological drought index (PHDI) are used to define hydrologic conditions for the Brazos River Basin SB3 environmental flow standards [16, 17, 18]. The PHDI as reported by the National Weather Service is based on a scale from -6.0 to 6.0 representing moisture conditions ranging from extremely dry to extremely wet. A regional PHDI was calculated for the Lower, Middle, and Upper Brazos River Basin from ranked PHDI values for a period of record from 1895 through 2010 to determine the ranges shown in Table 8.3 defining dry, average, and wet conditions [17, 18]. These ranges represent percentages of time of 25%, 50%, and 25% for wet, average, and dry conditions. Control points Camer and Hemp are in the Lower Basin. The determination of hydrologic condition occurs once for each season based on the PHDI at the end of the preceding season.

The seven groups of river systems for which SB3 EFS have been established to date are listed in Table 4.3 of *Reference Manual* Chapter 4. The Brazos River and its tributaries are the only river system for which the PHDI is employed to define hydrologic conditions. Cumulative river flow over the preceding 12 months or preceding reservoir storage contents are used to define hydrologic conditions in the other SB3 flow standards.

Table 8.3
Hydrologic Conditions Defined by PHDI Ranges

Geographic Area	Lower 25% PHDI Dry Condition	25% to 50% Average	Upper 50% PHDI Wet Condition
Upper Basin	less than -1.78	-1.78 to 2.18	greater than 2.18
Middle Basin	less than -1.95	-1.95 to 2.39	greater than 2.39
Lower Basin	less than -1.73	-1.73 to 2.13	greater than 2.13

Application of SB3 EFS Metrics to Set Instream Flow Targets

The metrics presented in Tables 8.1 and 8.2 are illustrative of the general framework within which SB3 EFS are being established by the TCEQ, its partner agencies, expert science teams, and stakeholder committees. However, the metrics are employed a little differently between the different river systems for which standards have been established to date. The *SIM/SIMD* modeling features discussed later in this chapter are designed to provide flexibility in accommodating variations in the definition and employment of the metrics.

The priority date established for the SB3 EFS for the Brazos River Basin is March 12, 2012 [16]. The priority is based on the date that the appointed expert science and stakeholder committees submitted recommendations to the TCEQ. The criterion for assigning priorities has been consistent for all of the river systems.

The SB3 EFS set target minimum instream flow limits. The following paragraphs outline the rules by which the metrics in Tables 8.1 and 8.2 are employed to set target minimum instream flow limits. The flow rate limits are expressed in units of cubic feet per second (cfs) and cumulative flow volumes are in acre-feet (af).

The SB3 standards for the Brazos River Basin apply the subsistence and base flow limits differently for dry hydrologic conditions than for average and wet hydrologic conditions. The subsistence flow limits of 32 cfs and 510 cfs in Tables 8.1 and 8.2 are applied with the 50% rule for dry conditions but are not employed at all for average and wet conditions.

The subsistence and base flow limits are applied as follows in the Brazos SB3 EFS.

- Under average or wet hydrologic conditions, the minimum instream flow limit is set at the base flow limit which varies seasonally as shown in Tables 8.1 and 8.2. The subsistence flow limits are not considered.
- Under dry conditions, the subsistence flow limit is applied if observed stream flow at the specified gage is less than or equal to the subsistence flow limit. The base flow limit applies if the actual flow equals or exceeds the base flow limit. The 50% rule is applied for dry hydrologic conditions for all three seasons if observed stream flow at the specified gage is greater than the subsistence flow limit and less than the base flow limit. The minimum instream flow limit is set equal to the subsistence flow limit plus 50 percent of the difference between the actual flow and subsistence flow limit.

Concepts and parameters for initiating, tracking, and terminating high flow pulses for the pulse flow component of SB3 EFS are described in Chapter 6 of this *Daily Manual*. The metrics defining pulse flow requirements adopted for the pulse flow component of the SB3 EFS at the gage sites on the Little River near Cameron and Brazos River near Hempstead (control points Camer and Hemp) are tabulated in columns 5, 6, and 7 of Tables 8.1 and 8.2.

Modeling SB3 Environmental Flow Standards

Senate Bill 3 (SB3) environmental flow standards (EFS) have been established at 19 USGS gaging stations on the Brazos River and its tributaries [7, 17]. The EFS at two of these 19 sites are summarized in Tables 8.1 and 8.2 and adopted for the following example. The objective here is to illustrate WRAP modeling capabilities using realistic datasets. The input data for these SB3 EFS may be further refined in the future in the actual Brazos WAM.

The environmental flow standards (EFS) for control points Camer and Hemp are modeled as described in this section using *IF*, *HC*, *HI*, *ES*, and *PF* records. The *SIMD* input records described here defining two new *IF* record water rights can be inserted any place in the sets of water right input records of the DAT file replicated as Table 7.3 of the preceding Chapter 7. The hydrologic index *HI* records defining hydrologic conditions for the *HC*, *ES* and *PF* records are added to the *SIMD* hydrology DSS input file.

IF, *HC*, *ES*, and *HI* records are described in Chapter 3 of the *Users Manual* and are applicable in both monthly *SIM* and daily *SIMD* simulations. *PF* and *PO* records are described in Chapter 4 of the *Users Manual* and are applicable only in a daily *SIMD* simulation. The remainder of this chapter includes both monthly and daily simulations that incorporate only the subsistence and base flow components of the EFS and a daily simulation that incorporates all flow regime components including high pulse flows.

Wurbs and Hoffpauir [6] describe the establishment of SB3 environmental flow standards by the Texas water management community and investigate methods for incorporating the EFS in the WAMs. The Brazos WAM served as a case study. The *HC* and *ES* records and associated computational routines were added to *SIM* and *SIMD* during 2018 and thus were not available for the earlier study. Combinations of multiple water right *WR* (type 8 rights), target options *TO*, flow switch *FS*, daily water rights *DW*, and daily options *DO* records were used to model the subsistence and base flow components of the EFS rather than *HC* and *ES* records. The 2013 report [6] documents the inaugural application of the *PF* and *PO* records and associated pulse tracking routines, which have since been significantly refined along with other features of *SIMD*.

Instream Flow IF Record Water Rights Added to the SIM/SIMD Input DAT File

The SB3 environmental flow standards summarized in Tables 8.1 and 8.2 are modeled as the two instream flow *IF* record water rights presented in Table 8.4, which are labeled with water right identifiers EFS-1 and EFS-2. The two *IF* record rights in the original *Fundamentals Manual* example are removed. Each of the two new instream flow rights consists of an *IF* record followed by a *HC* record, four *ES* records, and nine *PF* records. The two sets of input records describing the two instream flow rights EFS-1 and EFS-2 in Table 8.4 can be inserted any place in the water right section of the *SIM* or *SIMD* input DAT file of Table 7.3.

Table 8.4
 DAT File Input Records for Two *IF* Record Water Rights

```

**      1      2      3      4      5      6      7      8      9      10
**34567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
**-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!
IF Camer  -99.      999999      EFS-1
**
HC Hemp  1 HI  0 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.
ES BASE1  110.   110.   140.   140.   140.   140.   97.    97.    97.    97.   110.   110.
ES BASE2  190.   190.   310.   310.   310.   310.  160.   160.   160.   160.   190.   190.
ES BASE3  460.   460.   760.   760.   760.   760.  330.   330.   330.   330.   460.   460.
**
PF  1 1  1080.  6680.  8  1  0  11  2  0  0  2  0  3      Winter,HC1,Camer
PF  1 2  1080.  6680.  8  3  0  11  2  0  0  2  0  3      Winter,HC2,Camer
PF  1 3  2140.  14900. 10  2  0  11  2  0  0  2  0  3      Winter,HC3,Camer
PF  1 1  3200.  23900. 12  1  0  3  6  0  0  2  0  3      Spring,HC1,Camer
PF  1 2  3200.  23900. 12  3  0  3  6  0  0  2  0  3      Spring,HC2,Camer
PF  1 3  4790.  38400. 14  2  0  3  6  0  0  2  0  3      Spring,HC3,Camer
PF  1 1  560.   28600. 6  1  0  7  10  0  0  2  0  3      Summer,HC1,Camer
PF  1 2  560.   28600. 6  3  0  7  10  0  0  2  0  3      Summer,HC2,Camer
PF  1 3  990.   55500. 8  2  0  7  10  0  0  2  0  3      Summer,HC3,Camer
**
**-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!
IF Hemp  -9.      999999      EFS-2
**
HC Hemp  1 HI  0 M  J  N      0.0  1.5  2.5  -9.
**
ES SF501  510.   510.   510.   510.   510.   510.   510.   510.   510.   510.   510.   510.   510.
ES BASE1  920.   920.   1130.  1130.  1130.  1130.  950.   950.   950.   950.   920.   920.
ES BASE2  1440.  1440.  1900.  1900.  1900.  1900.  1330.  1330.  1330.  1330.  1440.  1440.
ES BASE3  2890.  2890.  3440.  3440.  3440.  3440.  2050.  2050.  2050.  2050.  2890.  2890.
**
PF  1 1  5720.  49800. 8  1  0  11  2  0  0  2  0  0      Winter,HC-1,Hemp
PF  1 2  5720.  49800. 8  3  0  11  2  0  0  2  0  0      Winter,HC-2,Hemp
PF  1 3  11200. 125000. 10  2  0  11  2  0  0  2  0  0      Winter,HC-3,Hemp
PF  1 1  85300. 23900. 13  1  0  3  6  0  0  2  0  0      Spring,HC-1,Hemp
PF  1 2  85300. 23900. 13  3  0  3  6  0  0  2  0  0      Spring,HC-2,Hemp
PF  1 3  16800. 38400. 19  2  0  3  6  0  0  2  0  0      Spring,HC-3,Hemp
PF  1 1  2620.  17000. 7  1  0  7  10  0  0  2  0  0      Summer,HC-1,Hemp
PF  1 2  2620.  17000. 7  3  0  7  10  0  0  2  0  0      Summer,HC-2,Hemp
PF  1 3  5090.  40900. 9  2  0  7  10  0  0  2  0  0      Summer,HC-3,Hemp
**
**-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!

```

The two hydrologic condition *HC* records reference hydrologic index *HI* records stored in the hydrology DSS input file. The same *HI* records, containing monthly series of the numbers 1.0, 2.0, and 3.0 representing dry, average, and wet conditions, are used by both *IF* record rights.

The *IF* records for instream flow rights EFS-1 and EFS-2 in Table 8.4 have -99 or -9 entered for AMT in *IF* record field 3, meaning an annual target volume is not entered but rather an alternative approach using *HC*, *ES*, and *PF* records is being employed to set monthly or daily targets. A negative number in *IF* record field 3 is required to switch to the *HC/ES/PF* record modeling strategy. Although the *IF* record fields 3 and 4 annual amount AMT and USE are not applicable with *HC/ES/PF* records, the other *IF* record fields are still valid. Other auxiliary water right records such as *WS*, *DI*, *IS*, *IP*, and *FS* records may be used to modify instream flows targets set with *HC*, *ES*, and/or *PF* records, but these options are not employed in this example.

Priorities of 999999 are assigned on the *IF* records to make EFS-1 and EFS-2 junior to all other water rights in the dataset. The priority set by the actual SB3 environmental flow standards is March 2012 (201203). However, the DAT file of Table 7.3 includes water rights WR-25, WR-26, WR-27, and WR-28 that refill reservoir storage with priorities of 888888. Flood control operations are also more junior. Thus, EFS-1 and EFS-2 would not be the most junior rights if assigned their actual priorities of March 2012 (201203). Of course, *SIMD* allows any priorities.

The DAT file input records in Table 8.4 comprise two *IF* record rights which are labeled EFS-1 and EFS-2. The *SIMD* simulation results output files will report the final targets and target shortages for these two instream flow rights. Alternatively, the subsidence and base flow components could be modeled with an *IF* record and accompanying set of *HC* and *ES* records while the pulse flow component is modeled with a separate *IF* record and set of *PF* records. This alternative approach employing multiple *IF* records allow separate targets to be recorded in the *SIMD* output file for the different components of the environmental flow standard.

Hydrologic Index HI Records in Hydrology Input DSS File

Of the several river systems with SB3 EFS established to date, the Brazos SB3 EFS are the only EFS that use the Palmer hydrologic drought index (PHDI) to define hydrologic conditions. The EFS for the other river systems use either 12-month preceding stream flow volume or the volume of preceding reservoir storage contents to define hydrologic conditions.

The Brazos EFS expert science team [16] compiled relevant PHDI data during development of the EFS from a National Weather Service database of regional period-of-record PHDI monthly time series data. Weighted PHDI averages for relevant regions were adopted for EFS sites. Dry, wet, and average hydrologic conditions are defined based on the PHDI during the driest 25% and wettest 25% of the months and the middle remaining 50% of the months during the historical period-of-record. The ranges for dry, average, and wet conditions are defined separately for the Upper, Middle, and Lower Brazos River Basin. The statistical analyses of PHDI were performed independently of the WRAP modeling system.

HI record indices of 1, 2, and 3 are used in the *SIMD* input dataset to represent the three PHDI ranges shown in Table 8.3. Hydrologic conditions are defined as (1) dry, (2) average, or (3) wet based on which of the three ranges of PHDI (Table 8.3) that the PHDI falls within during specified months of the 1940-2017 hydrologic period-of-analysis. Control points Camer and Hemp are both located in the Lower Basin and use the same *HI* record 1940-2017 hydrologic index sequence. The control point identifier Hemp was arbitrarily adopted for the single shared *HI* record in the hydrology input DSS file for the example.

The hydrologic index *HI* record stored in the *SIM/SIMD* input DSS file contains values of either 1.0, 2.0, or 3.0 for each of the 936 months of the 1940-2017 hydrologic period-of-analysis, which represent dry (1.0), average (2.0), or wet (3.0) hydrologic conditions. The input parameter DSSHI in *JO* record field 6 specifies reading of *HI* records from the DSS file. The following *HI* identifier record is inserted in the DAT file of Table 7.3 between the *JO* and *OF* records to provide an identifier used to reference the *HI* record in the DSS input record.

HI Hemp

Hydrologic Conditions Defined by HC and HI Records

Environmental standard *ES* and pulse flow *PF* records reference hydrologic conditions defined by a hydrologic condition *HC* record. The *HC* record is described in the *Users Manual* Chapter 3 and *Reference Manual* Chapter 4. *HC* record parameters are listed in Table 8.5.

Table 8.5
Hydrologic Condition *HC* Record Input Parameters

Field	Columns	Parameter	Parameter Description
2	3-8	CPHC	Control point identifier. Default is <i>IF</i> record field 2. Multiple control points are listed on an auxiliary HCCP record.
3	12	ESV	Variable used to select flow regime component: 1 regulated flow, -1 regulated flow excluding reservoir releases, 2 naturalized flow, 3 HCV without summation for NHCM months, 4 HCV with NHCM summation.
4	13-16	HCV	Variable used to define hydrologic condition: RF regulated flow, RR regulated flow excluding reservoir releases, NF naturalized flow, ST reservoir storage, HI hydrologic index on <i>HI</i> records, WR target for a specified <i>WR</i> record type 8 right.
5	17-20	NMCM	Number of preceding months for RF, RR, or NF summations.
6-17	21-32	HCM(M), M=1,12	Selection of months in which to update the hydrologic index.
18-27	33-112	HCL	Limits of HCV ranges defining hydrologic conditions.

Two *HC* records are included in the *SIMD* input DAT file input records shown in Table 8.4 to define hydrologic conditions for control points Camer and Hemp, respectively. Only one 1940-2017 series of *HI* record monthly hydrologic indices with values of 1.0, 2.0, or 3.0 is included in the DSS file since the same indices are used for both control points Camer and Hemp. The control point identifier Hemp is adopted for the *HI* records, though any identifier of six characters or less could be adopted for *HI* field 2 and the connecting *HC* record field 2. *HI* record control point identifiers, like all control points, must also be defined by a *CP* record.

The default *HC* record control point is the *IF* record field 2 control point. HCV options RF, RR, and NF can be defined as the summation of stream flow volumes in acre-feet/month at multiple control points by entering the term HCCP for parameter CPHC in *HC* record field 2. The identifiers of the multiple control points are then listed on a HCCP record.

HI is entered for input parameter HCV on the *HC* records indicating that a hydrologic index is provided on *HI* records for each month of the hydrologic period-of-analysis. The *HI* records are labeled with the control point identifier Hemp. The hydrologic condition is initially set at the beginning of the simulation (January 1940) based on the *HI* record value for January 1940 and updated at the beginning of March, July, and November of each year based on the *HI*

record values for those months during each year. The following three hydrologic conditions are defined based on which of the following ranges the HCV falls within.

hydrologic condition 1 (dry)	$0.5 \leq \text{HCV} \leq 1.5$
hydrologic condition 2 (average)	$1.5 \leq \text{HCV} \leq 2.5$
hydrologic condition 3 (wet)	$2.5 \leq \text{HCV} \leq 3.5$

The *HI* record indices for HCV are either 1.0, 2.0, or 3.0 for each of the 936 months of 1940-2017. Thus, the values are read from the *HI* records for March, July, and November of each year will fall within one of the three ranges shown above defined on the *HC* records. March, July, and November are the beginning of the Spring (March through June), Summer (July through October), and Winter (November through February) seasons. The hydrologic condition (dry, average, wet) applies throughout an entire four-month season.

The specifications described in the preceding paragraph are expressed on the *HC* records by entries for HCM(month) of M for March, J for July, and N for November in fields 8, 12, and 16 (columns 23, 27, and 31) and entries for the HCL limits of 1.5, 2.5, and -9.0 in fields 18, 19, and 20. The -9.0 is a standard HCL entry expressing no upper limit which is the same as an infinitely large upper limit. Entering 3.5 for the third HCL rather than -9.0 will work just as well and yield the same simulation results.

As indicated by Table 8.5, the HCV options in *HC* record field 4 allow various different variables to be used alternatively to define hydrologic conditions. The HCV=HI option employed in this example basically consists of defining hydrologic conditions independently of the WAM simulation. The hydrologic conditions at relevant control points for each month of the hydrologic period-of-analysis are pre-determined and recorded on *HI* records. The choice of hydrologic index employed to define hydrologic conditions happened to be the PHDI for the Brazos SB3 EFS but could conceivably be various other measured or computed parameters. Regardless of hydrologic condition parameter adopted, with HCV=HI, the hydrologic conditions are specified externally to the WRAP/WAM simulation model and input on *HI* records.

Alternatively, hydrologic conditions can be defined based on regulated or naturalized stream flows in the simulation model over a specified number of months at one or more specified control points or preceding reservoir storage capacity at one or more specified control points (HCF = RF, RR, NF, or ST). The HCF=WR option allows hydrologic conditions to be defined based the target computed by a specified water right using any of the target setting options provided by the WRAP simulation model.

Subsistence and Base Flow Requirements Defined By ES Records

The *ES* record is described in Chapter 3 of the *Users Manual* and Chapter 4 of the *Reference Manual*. *ES* record parameters are listed in Table 8.6 on the next page. The subsistence flow quantities (32 cfs and 510 cfs) in column 2 of Tables 8.1 and 8.2 and base flow quantities in column 4 of Tables 8.1 and 8.2 are replicated on the *ES* records of Table 8.4.

Four *ES* records are provided for the *IF* record at control point Camer, and four *ES* records are provided for the *IF* record at control point Hemp. The first *ES* record in each of the

two (Camer and Hemp) instream flow datasets consists of the subsistence flow limits of 32 cfs and 510 cfs for dry conditions to be employed with the 50% rule (ESC=SF50, ESHC=1). In general, subsistence flow limits may be employed for all hydrologic conditions. However, the Brazos SB3 EFS apply subsistence flow limits only during dry conditions. Although subsistence flows may vary seasonally, the Brazos SB3 EFS adopts a constant 32 cfs at Camer and 510 cfs at Hemp throughout the year.

Table 8.6
Environmental Standard *ES* Record Input Parameters

Field	Columns	Parameter	Parameter Description
2	4-7	ESF	SF50 (subsistence flow with 50% rule), SUBS (subsistence), BASE (base flow), HIGH (high flow), PFES (only <i>PF</i> records)
3	8	ESHG	Hydrologic condition.
4-15	9-104	ESQ(M) M=1,12	Instream flow quantities in cfs for each of month of the year.
16	105-108	ESAF	Activates option to enter ESQ(M) in acre-feet rather than cfs.
17	109-116	ESQX	Multiplier or conversion factor for ESQ(M).

Seasonally varying base flow limits are applied for each of the three hydrologic conditions. A separate base flow *ES* record (ESC=BASE in field 2) is provided for each of the hydrologic conditions (ESHG=1,2,3 in *ES* record column 8). The base flow instream flow target limits for each of the 12 months of the year ESQ(M) in cfs are entered in fields 4 through 15.

The following *IF* record water right discussed on page 191 is an example of a special case in which an *IF* record has only one *ES* record and no ESF is entered in *ES* record field 2.

```

IF Camer      -9                      IF-1
ES           4.9726 4.9726 4.9726 4.9726 4.9726 4.9726 4.9726 4.9726 4.9726 4.9726 4.9726 4.9726

```

In this special case of only one *ES* record, the ESF defaults (blank *ES* field 2) to SUBS which has the same effect as specifying either SUBS or BASE. Otherwise, with more than one *ES* record for an *IF* record right, ESF must be specified in *ES* record field 2 for each and every *ES* record.

The flow regime selection variable ESV is selected in *HC* record field 3, with the default being regulated flow at the priority of the water right (*IF* record) in the priority-based simulation. Adoption of the default ESV option 1 (regulated flow) is assumed in the following discussion. The following rules are applied each month in a *SIM* or *SIMD* monthly simulation and each day in a *SIMD* daily simulation. The rules followed in the *SIM* or *SIMD* simulation for employing subsistence and base flow limits from the environmental flow *ES* records are outlined as follows.

1. If the simulated regulated flow (ESV) is less than or equal to the subsistence flow limit, the minimum flow limit target is set equal to the subsistence flow limit.
2. If the regulated flow exceeds the subsistence flow limit but is less than the base flow limit, the following two alternative rules are possible.

- a. The minimum instream flow limit is set equal to the subsistence flow limit if SUBS is entered for ESC in *ES* record field 2.
- b. The 50 percent rule is applied if SF50 is entered for ESC in *ES* record field 2.
3. If the regulated flow (ESV) equals or exceeds the base flow limit, the minimum instream flow target is set at either the base flow limit (*ES* record), high flow (*ES* record), or pulse flow (*PF* record) limit, whichever is largest.
4. If there is no *ES* record with ESF of SUBS or SF50 specifying a subsistence flow EFS component for a particular hydrologic condition, the instream flow 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).

The 50 percent (50%) rule adopted in the SB3 EFS for various river systems and the *SIM/SIMD* simulation model is applicable only when the actual measured or simulated regulated stream flow is higher than the subsistence flow limit but lower than the base flow limit. The 50% rule is defined as follows.

1. If the actual measured stream flow or *SIM/SIMD* computed regulated flow at the gage site (control point) is less than or equal to the subsistence flow limit, the target minimum flow limit is set at the subsistence flow limit.
2. If the actual or regulated flow 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 actual flow and subsistence flow limit.
3. If the actual or regulated flow equals or exceeds to the base flow limit, the target is set at either the base flow limit or high pulse flow limit.

High Pulse Flow Requirements Defined By *ES* Records

The *ES* record field 2 ESF options described in *Reference Manual* Chapter 4 and *Users Manual* Chapter 3 also include a high flow component of the flow regime activated by ESF = HAnn or HSnn, where nn is a maximum limit on the number of months or days that the high flow target is employed each year or season. With one or both of these options activated, the high flow ESQ limit is adopted as the instream flow target if the regulated flow equals or exceeds the high flow rate ESQ limit and the nn months or days limit has not been reached.

PF and *PO* records are designed to model the SB3 EFS high pulse flow requirements but require a daily simulation. The *ES* record high flow options are included in *SIM/SIMD* to provide additional monthly modeling flexibility if and as needed, but do not closely fit the SB3 EFS format. The example does not employ the *ES* record high flow options.

High Pulse Flow Requirements Defined By *PF* Records

The pulse flow *PF* and pulse options *PO* records are described in Chapter 4 of the *Users Manual* and Chapter 6 of this *Daily Manual*. *PF* and *PO* record parameters are listed and defined in Tables 6.1 and 6.2 of Chapter 6. The pulse flow quantities in columns 5, 6, and 7 of Tables 8.1 and 8.2 are replicated on the *PF* records of Table 8.4.

The basic *SIMD* high pulse flow modeling features are controlled by *PF* records. Refinements in defining the details of the pulse flow requirements are activated by supplemental options available on the *PO* record. Defaults for *PO* record parameters are automatically activated by *SIMD* if no *PO* record is provided. Each *PF* record is allowed one *PO* record to refine the pulse flow specifications. However, no *PO* records are used in the example.

Each *PF* record represents a season and a hydrologic condition. Combinations of three seasons and three hydrologic conditions result in nine *PF* records for control point Camer and nine *PF* records for control point Hemp. The same *HC* record defining hydrologic conditions is referenced by both the *ES* and *PF* records for the *IF* record water rights.

Modeling and Analysis of Subsistence and Base Flow Standards

HC and *ES* records are applicable in either a *SIM* or *SIMD* monthly simulation or *SIMD* daily simulation. *PF* records are applicable in only a *SIMD* daily simulation. Instream flow targets are computed for each month of a *SIM* or *SIMD* monthly simulation and each day of a *SIMD* daily simulation. The following discussion focuses on monthly and daily simulation of the subsistence and base flow components of the Senate Bill 3 (SB3) environmental flow standards (EFS). High pulse flow components of the EFS are addressed later in the chapter.

SIM can be executed with an input dataset designed for a daily *SIMD* simulation. The records that are applicable only to a daily simulation are skipped over in the monthly *SIM* simulation. Messages are recorded in the message MSS file indicating which daily records were found but not used. Any other invalid record identifiers activate error messages and program termination. Unlike *SIM*, *SIMD* has no features for skipping daily-only DAT file input records. *SIMD* as well as *SIM* can perform a monthly simulation with a DAT file designed for a monthly simulation (no daily-only records), with both models providing the same simulation results.

The following discussion refers to a monthly *SIM* simulation and daily *SIMD* simulation with the *IF*, *HC*, *ES*, and *PF* records of Table 8.4 inserted in the DAT file of Table 7.3. *SIM* skips over the *PF* records. The daily *SIMD* simulation computes daily targets as specified by the DAT file input records in Tables 7.3 and 8.4. All daily simulation results variables, including targets, are aggregated to monthly quantities within *SIMD* for output to the monthly OUT file along with recording the daily quantities in the daily output SUB file. Both monthly and daily simulation results are also recorded in the DSS output file.

ES Record Target Results Table in Message MSS File

A -9.0 or any negative entry in *IF* record field 3 signals the modeling of instream flow standards with *HC*, *ES*, and/or *PF* records. A -99.0 in *IF* record field 3 activates the option of creating a table in the MSS file designed to facilitate convenient tracking of monthly *SIM* or daily *SIMD* determinations of *ES* record targets. The beginning of the MSS file table created by the -99.0 in *IF* record field 3 for water right EFS-1 is shown in Tables 8.7 and 8.8 for monthly *SIM* and daily *SIMD* simulations. Each line of these tables consists of information for water right EFS-1 for one month of the monthly simulation (Table 8.7) or one day of the daily simulation (Table 8.8). For the sake of brevity, only the beginning 12 months of the 936-month *SIM* and 35 days of the 28,490-day *SIMD* simulation are included in the tables.

Table 8.7
Beginning of ES Record Target Results Table from MSS File for Monthly SIM Simulation

Environmental Flow Standard Targets in cfs and acre-feet (af) for Selected Hydrologic Condition (HC) Subsistence Flow (SF), Base Flow (BF), and High Flow (HF) ESQ Limits from ES Records

WRID	Year	M	XRF(af)	HCV	HC	SF(cfs)	BF(cfs)	HF(cfs)	SF(af)	BF(af)	HF(af)	AMT(af)
EFS-1	1940	1	386.2	1.0	1	32.0	110.0	-9.0	1967.6	6763.6	0.0	1967.6
EFS-1	1940	2	12426.9	1.0	1	32.0	110.0	-9.0	1840.7	6327.3	0.0	6327.3
EFS-1	1940	3	28564.9	1.0	1	32.0	140.0	-9.0	1967.6	8608.3	0.0	8608.3
EFS-1	1940	4	58801.6	1.0	1	32.0	140.0	-9.0	1904.1	8330.6	0.0	8330.6
EFS-1	1940	5	85855.3	1.0	1	32.0	140.0	-9.0	1967.6	8608.3	0.0	8608.3
EFS-1	1940	6	150440.3	2.0	1	32.0	140.0	-9.0	1904.1	8330.6	0.0	8330.6
EFS-1	1940	7	331941.6	2.0	2	-9.0	160.0	-9.0	0.0	9838.0	0.0	9838.0
EFS-1	1940	8	0.0	3.0	2	-9.0	160.0	-9.0	0.0	9838.0	0.0	9838.0
EFS-1	1940	9	0.0	2.0	2	-9.0	160.0	-9.0	0.0	9520.7	0.0	9520.7
EFS-1	1940	10	47976.3	2.0	2	-9.0	160.0	-9.0	0.0	9838.0	0.0	9838.0
EFS-1	1940	11	355853.8	3.0	3	-9.0	460.0	-9.0	0.0	27371.9	0.0	27371.9
EFS-1	1940	12	594230.6	3.0	3	-9.0	460.0	-9.0	0.0	28284.3	0.0	28284.3

The 924 lines of data covering each month from 1941 through 2017 are omitted here.

Table 8.8
Beginning of ES Record Target Results Table from MSS File for Daily SIMD Simulation

Environmental Flow Standard Targets in cfs and acre-feet (af) for Selected Hydrologic Condition (HC) Subsistence Flow (SF), Base Flow (BF), and High Flow (HF) ESQ Limits from ES Records

WRID	Year	M	D	XRF(af)	HCV	HC	SF(cfs)	BF(cfs)	HF(cfs)	SF(af)	BF(af)	HF(af)	Target(af)
EFS-1	1940	1	1	0.0	1.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	2	55.6	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	3	0.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	4	0.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	5	0.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	6	0.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	7	0.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	8	28.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	9	929.2	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	1	10	43.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	11	142.3	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	102.9
EFS-1	1940	1	12	1461.1	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	1	13	0.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	14	52.6	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	15	1346.1	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	1	16	1846.1	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	1	17	0.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	18	1273.6	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	1	19	0.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	20	1843.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	1	21	0.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	22	0.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	23	1165.4	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	1	24	1627.2	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	1	25	0.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	26	1320.1	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	1	27	11.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	28	1278.7	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	1	29	13.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	1	30	1202.8	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	1	31	14.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	2	1	1220.2	1.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	2	2	7.0	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	63.5
EFS-1	1940	2	3	1400.5	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2
EFS-1	1940	2	4	4325.4	0.0	1	32.0	110.0	-9.0	63.5	218.2	0.0	218.2

The 28,455 lines of data covering each day from February 5, 1940 through December 31, 2017 are omitted here.

Each line of data in the MSS file table of Tables 8.7 and 8.8 includes:

- regulated flow (XRF) in acre-feet at control point Camer at the priority (999999) of water right EFS-1 in the priority-sequence simulation computations
- hydrologic condition variable (HCV) from *HI* record
- hydrologic condition (HC) specified by the HCV
- subsistence (SF) and base (BF) flows in both cfs and acre-feet
- high flows (HF) are all -9.0 and 0.0 since none are specified on the *ES* records
- the final selected instream flow target for the month or day

The number -9.0 in Tables 8.7 and 8.8 is used to indicate that values are not provided as input and are not relevant in the simulation. The number 0.0 in the tables refer to actual values of zero computed or adopted in the computations. The dataset contains no *ES* records with subsistence flow (ESF = SF50 or SUBS) for hydrologic conditions 2 and 3. Thus, for periods with hydrologic conditions 2 and 3 in effect, subsistence flow is not relevant to the computations, has no effect on the computations, and is flagged with an -9.0 in the MSS file table. A zero or blank field for one or more of the 12 ESQ(wr,es,m) on a *ES* record is treated as the number zero. A -9.0 can be entered in individual fields (months) of a *ES* record to indicate that no limit, zero or non-zero, is specified. Blanks or 0.0 are handled differently than -9.0 in the *ES* record fields.

Monthly Subsistence and Base Flow Targets and Shortages

Tables 8.9, 8.10, 8.11, and 8.12 consist of subsistence and base flow targets determined by a monthly *SIM* simulation and monthly means of the daily instream flow targets determined by a daily *SIMD* simulation. The subsistence and base flow instream flow targets are computed by *SIM* and *SIMD* as specified by the *HC* and *ES* records in Table 8.4 inserted in the DAT file of Table 7.3. The targets in Tables 8.9 and 8.10 are computed in a *SIM* simulation. The targets in Tables 8.11 and 8.12 are monthly means of daily targets from a daily simulation computed within *SIMD*. The pulse flow *PF* records are omitted in both simulations. With the DAT file containing only one *IF* record water right at each of two control points and no *PF* records, Tables 8.9 through 8.12 can be created with *TABLES* for either water rights or control points as follows.

	2IFT	1	0	0	1	2	0	0	0	1
	IDEN			EFS-1				EFS-2		
or	2IFT	1	0	0	0	2	0	0	0	1
	IDEN	Camer		Hemp						

The corresponding tables of instream flow shortages (2IFS) and supplied portion of instream flow targets (2IFF) in either acre-feet or cfs can be created with 2IFS and 2IFF records. *TABLES* handles the monthly aggregation of daily instream flow shortages differently for control points versus water rights. As indicated by Tables 5.3 and 5.4 of the *Reference Manual*, *SIM/SIMD* OUT and SUB output records for control points contain the instream flow target at the completion of the water rights priority sequence. Instream flow water right output records contain both targets and shortages for individual rights. For control points, instream flow shortages are computed within *TABLES* from regulated flows and targets read from the *SIM* or *SIMD* output OUT or SUB files. *TABLES* reads both targets and shortages from the instream flow water right output records in the *SIM* or *SIMD* output OUT or SUB files.

The ESQ(wr,es,m) in cubic feet per second (cfs) on the *ES* records are converted to acre-feet within *SIM* or *SIMD*. The CFS option on the *TABLES* time series records converts *SIM* simulation results quantities from units of acre-feet/period to cfs. The unit conversions reflect the different number of days in each of 12 months and the leap year difference for February.

Table 8.9
 Subsistence and Base Flow Targets (cfs) for EFS-1 at Camer from Monthly *SIM* Simulation

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	32.	110.	140.	140.	140.	140.	160.	160.	160.	160.	460.	460.	189.
1941	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	460.	460.	516.
1942	460.	460.	310.	310.	310.	310.	330.	330.	330.	330.	460.	460.	366.
1943	460.	460.	310.	310.	310.	310.	160.	160.	160.	160.	110.	46.	245.
1944	110.	110.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	207.
1945	190.	190.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	428.
1946	190.	190.	760.	760.	760.	760.	160.	160.	160.	160.	460.	460.	416.
1947	460.	460.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	264.
1948	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	110.	110.	207.
1949	110.	110.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	207.
1950	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1951	190.	190.	140.	32.	32.	32.	45.	32.	32.	32.	32.	32.	68.
1952	32.	32.	32.	140.	140.	32.	97.	33.	32.	32.	32.	110.	62.
1953	110.	110.	36.	140.	140.	140.	32.	97.	33.	97.	190.	190.	109.
1954	190.	190.	32.	32.	140.	32.	32.	32.	32.	32.	110.	32.	73.
1955	32.	110.	53.	140.	140.	140.	32.	97.	97.	32.	32.	32.	78.
1956	32.	32.	32.	32.	34.	70.	33.	97.	32.	32.	32.	44.	42.
1957	32.	32.	140.	140.	140.	140.	330.	330.	330.	330.	460.	460.	240.
1958	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	471.
1959	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1960	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1961	190.	190.	760.	760.	760.	760.	160.	160.	160.	160.	190.	190.	370.
1962	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1963	190.	190.	72.	140.	32.	32.	97.	97.	32.	32.	110.	110.	94.
1964	110.	110.	140.	140.	140.	140.	32.	97.	97.	97.	190.	190.	123.
1965	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1966	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1967	190.	190.	140.	53.	140.	32.	63.	97.	32.	97.	190.	190.	118.
1968	190.	190.	760.	760.	760.	760.	330.	330.	330.	330.	460.	460.	473.
1969	460.	460.	760.	760.	760.	760.	160.	160.	160.	160.	190.	190.	414.
1970	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1971	190.	190.	140.	140.	140.	32.	97.	32.	32.	97.	190.	190.	122.
1972	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1973	190.	190.	310.	310.	310.	310.	330.	330.	330.	330.	460.	460.	322.
1974	460.	460.	310.	310.	310.	310.	160.	160.	160.	160.	460.	460.	309.
1975	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	471.
1976	190.	190.	140.	140.	140.	140.	160.	160.	160.	160.	460.	460.	208.
1977	460.	460.	760.	760.	760.	760.	160.	160.	160.	160.	34.	32.	388.
1978	35.	110.	80.	57.	32.	140.	57.	97.	32.	32.	41.	32.	62.
1979	110.	110.	310.	310.	310.	310.	330.	330.	330.	330.	190.	190.	264.
1980	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	37.	58.	196.
1981	42.	110.	140.	140.	140.	140.	160.	160.	160.	160.	460.	460.	190.
1982	460.	460.	310.	310.	310.	310.	330.	330.	330.	330.	190.	190.	321.
1983	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1984	190.	190.	310.	310.	310.	310.	32.	32.	32.	97.	190.	190.	182.
1985	190.	190.	760.	760.	760.	760.	160.	160.	160.	160.	190.	190.	370.
1986	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	460.	460.	265.
1987	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	471.
1988	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	110.	110.	207.
1989	44.	110.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	201.
1990	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1991	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	460.	460.	265.
1992	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	460.	460.	516.
1993	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	471.
1994	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	460.	460.	265.
1995	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	471.
1996	190.	190.	140.	32.	32.	140.	97.	97.	97.	97.	190.	190.	124.

1997	190.	190.	760.	760.	760.	760.	330.	330.	330.	330.	460.	460.	473.
1998	460.	460.	760.	760.	760.	760.	62.	97.	97.	97.	190.	190.	390.
1999	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	110.	32.	200.
2000	32.	32.	60.	140.	140.	32.	32.	32.	32.	97.	190.	190.	84.
2001	190.	190.	760.	760.	760.	760.	160.	160.	160.	160.	190.	190.	370.
2002	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
2003	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
2004	190.	190.	310.	310.	310.	310.	330.	330.	330.	330.	460.	460.	322.
2005	460.	460.	760.	760.	760.	760.	160.	160.	160.	160.	52.	60.	392.
2006	46.	62.	140.	140.	140.	32.	97.	97.	97.	97.	32.	110.	91.
2007	110.	110.	310.	310.	310.	310.	330.	330.	330.	330.	460.	460.	309.
2008	460.	460.	310.	310.	310.	310.	97.	32.	32.	32.	190.	190.	226.
2009	190.	190.	62.	140.	34.	140.	97.	63.	97.	97.	190.	190.	123.
2010	190.	190.	760.	760.	760.	760.	160.	160.	160.	160.	190.	190.	370.
2011	190.	190.	140.	140.	52.	140.	50.	97.	97.	97.	32.	37.	104.
2012	110.	110.	310.	310.	310.	310.	97.	32.	32.	32.	32.	32.	143.
2013	110.	32.	32.	32.	41.	61.	97.	32.	32.	97.	190.	190.	79.
2014	190.	190.	46.	32.	140.	32.	160.	160.	160.	160.	190.	190.	137.
2015	190.	190.	310.	310.	310.	310.	330.	330.	330.	330.	460.	460.	322.
2016	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	460.	460.	516.
2017	460.	460.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	264.
MEAN	228.	232.	365.	367.	367.	363.	176.	177.	173.	177.	228.	227.	256.

Table 8.10
Subsistence and Base Flow Targets (cfs) for EFS-2 at Hemp from Monthly SIM Simulation

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	510.	920.	510.	611.	1130.	1130.	1330.	1330.	1330.	1330.	2890.	2890.	1327.
1941	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	2890.	2890.	2791.
1942	2890.	2890.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	2890.	2890.	2276.
1943	2890.	2890.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	510.	1636.
1944	920.	920.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1473.
1945	1440.	1440.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2314.
1946	1440.	1440.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	2890.	2890.	2314.
1947	2890.	2890.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1791.
1948	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	510.	1401.
1949	510.	920.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1438.
1950	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1951	1440.	1440.	510.	510.	510.	510.	510.	510.	510.	510.	510.	510.	660.
1952	510.	510.	510.	1130.	1130.	510.	510.	510.	510.	510.	510.	920.	648.
1953	920.	679.	1130.	510.	1130.	510.	510.	510.	510.	950.	1440.	1440.	856.
1954	1440.	1440.	510.	510.	516.	510.	510.	510.	510.	510.	510.	510.	661.
1955	510.	920.	510.	1130.	510.	510.	510.	510.	510.	950.	510.	510.	630.
1956	510.	510.	510.	510.	645.	510.	510.	510.	510.	510.	510.	510.	521.
1957	510.	510.	510.	1130.	1130.	1130.	2050.	2050.	2050.	2050.	2890.	2890.	1581.
1958	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2548.
1959	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1960	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1961	1440.	1440.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	1440.	1440.	2071.
1962	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1963	1440.	1440.	510.	1130.	547.	510.	510.	510.	510.	510.	510.	510.	714.
1964	510.	510.	1130.	510.	510.	510.	510.	510.	510.	510.	1440.	1440.	718.
1965	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1966	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1967	1440.	1440.	510.	510.	653.	510.	510.	510.	510.	510.	1440.	1440.	828.
1968	1440.	1440.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	2890.	2890.	2556.
1969	2890.	2890.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	1440.	1440.	2306.
1970	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1971	1440.	1440.	510.	510.	510.	510.	510.	510.	510.	510.	1440.	1440.	816.
1972	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1973	1440.	1440.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	2890.	2890.	2042.
1974	2890.	2890.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	2890.	2890.	2033.
1975	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2548.
1976	1440.	1440.	576.	1130.	1130.	1130.	1330.	1330.	1330.	1330.	2890.	2890.	1495.
1977	2890.	2890.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	510.	510.	2150.
1978	558.	920.	1130.	510.	510.	510.	510.	510.	510.	510.	510.	510.	598.
1979	920.	920.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	1440.	1440.	1715.
1980	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	510.	1401.

1981	510.	510.	510.	510.	1130.	1130.	1330.	1330.	1330.	1330.	2890.	2890.	1288.
1982	2890.	2890.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	1440.	1440.	2034.
1983	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1984	1440.	1440.	1900.	1900.	1900.	1900.	510.	510.	510.	950.	1440.	1440.	1318.
1985	1440.	1440.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	1440.	1440.	2071.
1986	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	2890.	2890.	1799.
1987	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2548.
1988	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	510.	1401.
1989	637.	920.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1449.
1990	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1991	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	2890.	2890.	1799.
1992	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	2890.	2890.	2791.
1993	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2548.
1994	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	2890.	2890.	1799.
1995	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2548.
1996	1440.	1440.	510.	510.	510.	510.	510.	510.	950.	510.	1440.	1440.	852.
1997	1440.	1440.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	2890.	2890.	2556.
1998	2890.	2890.	3440.	3440.	3440.	3440.	510.	510.	950.	950.	1440.	1440.	2103.
1999	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	510.	1401.
2000	510.	510.	510.	510.	1130.	758.	510.	510.	510.	510.	1440.	1440.	739.
2001	1440.	1440.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	1440.	1440.	2071.
2002	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
2003	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
2004	1440.	1440.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	2890.	2890.	2042.
2005	2890.	2890.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	510.	510.	2150.
2006	510.	510.	1130.	767.	1130.	510.	510.	510.	510.	950.	510.	510.	674.
2007	920.	708.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	2890.	2890.	1941.
2008	2890.	2890.	1900.	1900.	1900.	1900.	510.	510.	510.	510.	1440.	1440.	1515.
2009	1440.	1440.	510.	1130.	1130.	510.	510.	510.	528.	950.	1440.	1440.	958.
2010	1440.	1440.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	1440.	1440.	2071.
2011	1440.	1440.	510.	510.	510.	510.	510.	510.	510.	510.	510.	510.	660.
2012	920.	920.	1900.	1900.	1900.	1900.	510.	510.	510.	510.	510.	510.	1041.
2013	920.	510.	510.	510.	510.	510.	510.	510.	510.	950.	1440.	1440.	738.
2014	1440.	1440.	510.	510.	1130.	510.	1330.	1330.	1330.	1330.	1440.	1440.	1145.
2015	1440.	1440.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	2890.	2890.	2042.
2016	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	2890.	2890.	2791.
2017	2890.	2890.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1791.
MEAN	1612.	1625.	1935.	1955.	1986.	1938.	1285.	1285.	1296.	1324.	1591.	1596.	1618.

Table 8.11
Subsistence and Base Flow Targets (cfs) for EFS-1 at Camer from Daily *SIMD* Simulation

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	60.	63.	80.	122.	84.	110.	160.	160.	160.	160.	460.	460.	174.
1941	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	460.	460.	516.
1942	460.	460.	310.	310.	310.	310.	330.	330.	330.	330.	460.	460.	366.
1943	460.	460.	310.	310.	310.	310.	160.	160.	160.	160.	82.	78.	245.
1944	102.	110.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	206.
1945	190.	190.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	428.
1946	190.	190.	760.	760.	760.	760.	160.	160.	160.	160.	460.	460.	416.
1947	460.	460.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	264.
1948	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	61.	32.	196.
1949	55.	43.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	197.
1950	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1951	190.	190.	49.	36.	84.	106.	32.	32.	43.	32.	32.	32.	71.
1952	32.	32.	40.	66.	111.	108.	42.	32.	32.	32.	42.	72.	54.
1953	71.	47.	50.	75.	81.	104.	75.	55.	50.	65.	190.	190.	88.
1954	190.	190.	32.	57.	79.	32.	32.	32.	33.	45.	68.	32.	68.
1955	44.	56.	56.	57.	112.	127.	58.	50.	62.	50.	33.	37.	62.
1956	49.	59.	32.	47.	106.	59.	32.	40.	32.	32.	49.	65.	50.
1957	41.	50.	109.	106.	96.	140.	330.	330.	330.	330.	460.	460.	233.
1958	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	471.
1959	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1960	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1961	190.	190.	760.	760.	760.	760.	160.	160.	160.	160.	190.	190.	370.
1962	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1963	190.	190.	84.	107.	140.	85.	56.	33.	41.	47.	64.	65.	91.
1964	63.	99.	140.	111.	100.	71.	50.	63.	64.	78.	190.	190.	102.

1965	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1966	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1967	190.	190.	91.	91.	108.	68.	65.	44.	65.	63.	190.	190.	112.
1968	190.	190.	760.	760.	760.	760.	330.	330.	330.	330.	460.	460.	473.
1969	460.	460.	760.	760.	760.	760.	160.	160.	160.	160.	190.	190.	414.
1970	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1971	190.	190.	84.	107.	80.	40.	72.	59.	88.	83.	190.	190.	114.
1972	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1973	190.	190.	310.	310.	310.	310.	330.	330.	330.	330.	460.	460.	322.
1974	460.	460.	310.	310.	310.	310.	160.	160.	160.	160.	460.	460.	309.
1975	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	471.
1976	190.	190.	91.	112.	119.	113.	160.	160.	160.	160.	460.	460.	198.
1977	460.	460.	760.	760.	760.	760.	160.	160.	160.	160.	75.	62.	394.
1978	63.	61.	80.	71.	72.	81.	67.	44.	43.	38.	90.	64.	64.
1979	110.	110.	310.	310.	310.	310.	310.	330.	330.	330.	190.	190.	264.
1980	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	70.	102.	203.
1981	89.	110.	117.	122.	88.	97.	160.	160.	160.	160.	460.	460.	182.
1982	460.	460.	310.	310.	310.	310.	330.	330.	330.	330.	190.	190.	321.
1983	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1984	190.	190.	310.	310.	310.	310.	37.	32.	32.	81.	190.	190.	181.
1985	190.	190.	760.	760.	760.	760.	160.	160.	160.	160.	190.	190.	370.
1986	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	460.	460.	265.
1987	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	471.
1988	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	65.	33.	196.
1989	54.	77.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	200.
1990	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
1991	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	460.	460.	265.
1992	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	460.	460.	516.
1993	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	471.
1994	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	460.	460.	265.
1995	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	190.	190.	471.
1996	190.	190.	79.	58.	86.	121.	68.	53.	82.	97.	190.	190.	116.
1997	190.	190.	760.	760.	760.	760.	330.	330.	330.	330.	460.	460.	473.
1998	460.	460.	760.	760.	760.	760.	69.	71.	70.	81.	190.	190.	385.
1999	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	42.	32.	194.
2000	44.	41.	75.	93.	68.	64.	34.	32.	43.	50.	190.	190.	77.
2001	190.	190.	760.	760.	760.	760.	160.	160.	160.	160.	190.	190.	370.
2002	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
2003	190.	190.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	220.
2004	190.	190.	310.	310.	310.	310.	330.	330.	330.	330.	460.	460.	322.
2005	460.	460.	760.	760.	760.	760.	160.	160.	160.	160.	110.	75.	398.
2006	44.	68.	56.	99.	125.	135.	74.	63.	50.	68.	40.	61.	74.
2007	99.	102.	310.	310.	310.	310.	330.	330.	330.	330.	460.	460.	308.
2008	460.	460.	310.	310.	310.	310.	62.	66.	45.	64.	190.	190.	230.
2009	190.	190.	78.	120.	76.	93.	69.	39.	66.	95.	190.	190.	116.
2010	190.	190.	760.	760.	760.	760.	160.	160.	160.	160.	190.	190.	370.
2011	190.	190.	116.	100.	123.	88.	66.	61.	39.	80.	32.	59.	95.
2012	52.	57.	310.	310.	310.	310.	91.	40.	44.	34.	32.	32.	135.
2013	49.	38.	41.	48.	96.	35.	69.	32.	77.	60.	190.	190.	77.
2014	190.	190.	54.	46.	86.	58.	160.	160.	160.	160.	190.	190.	137.
2015	190.	190.	310.	310.	310.	310.	330.	330.	330.	330.	460.	460.	322.
2016	460.	460.	760.	760.	760.	760.	330.	330.	330.	330.	460.	460.	516.
2017	460.	460.	310.	310.	310.	310.	160.	160.	160.	160.	190.	190.	264.
MEAN	226.	228.	359.	362.	365.	363.	174.	171.	172.	175.	227.	226.	254.

Table 8.12
Subsistence and Base Flow Targets (cfs) for EFS-2 at Hemp from Daily *SIMD* Simulation

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	516.	833.	511.	648.	834.	944.	1330.	1330.	1330.	1330.	2890.	2890.	1284.
1941	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	2890.	2890.	2791.
1942	2890.	2890.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	2890.	2890.	2276.
1943	2890.	2890.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	542.	1638.
1944	920.	920.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1473.
1945	1440.	1440.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2314.
1946	1440.	1440.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	2890.	2890.	2314.
1947	2890.	2890.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1791.
1948	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	510.	1401.

1949	642.	727.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1434.
1950	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1951	1440.	1440.	570.	572.	631.	717.	510.	510.	539.	510.	510.	510.	700.
1952	510.	510.	536.	787.	744.	636.	517.	510.	510.	510.	578.	677.	586.
1953	686.	654.	838.	593.	1104.	561.	616.	510.	539.	642.	1440.	1440.	803.
1954	1440.	1440.	510.	634.	795.	510.	510.	510.	510.	510.	585.	510.	701.
1955	510.	742.	580.	786.	718.	625.	510.	514.	583.	731.	510.	510.	609.
1956	510.	510.	510.	510.	650.	510.	510.	510.	510.	510.	537.	592.	531.
1957	510.	642.	530.	892.	1130.	1130.	2050.	2050.	2050.	2050.	2890.	2890.	1574.
1958	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2548.
1959	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1960	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1961	1440.	1440.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	1440.	1440.	2071.
1962	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1963	1440.	1440.	536.	744.	662.	789.	510.	510.	510.	531.	557.	510.	723.
1964	553.	696.	856.	701.	600.	613.	510.	510.	649.	564.	1440.	1440.	761.
1965	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1966	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1967	1440.	1440.	510.	753.	674.	784.	553.	510.	518.	538.	1440.	1440.	879.
1968	1440.	1440.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	2890.	2890.	2556.
1969	2890.	2890.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	1440.	1440.	2306.
1970	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1971	1440.	1440.	521.	593.	625.	558.	581.	681.	510.	567.	1440.	1440.	863.
1972	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1973	1440.	1440.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	2890.	2890.	2042.
1974	2890.	2890.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	2890.	2890.	2033.
1975	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2548.
1976	1440.	1440.	704.	1018.	1130.	981.	1330.	1330.	1330.	1330.	2890.	2890.	1484.
1977	2890.	2890.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	510.	559.	2155.
1978	673.	765.	777.	620.	510.	613.	510.	751.	510.	510.	510.	510.	604.
1979	722.	920.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	1440.	1440.	1698.
1980	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	510.	1401.
1981	510.	510.	720.	702.	830.	1006.	1330.	1330.	1330.	1330.	2890.	2890.	1286.
1982	2890.	2890.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	1440.	1440.	2034.
1983	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1984	1440.	1440.	1900.	1900.	1900.	1900.	510.	510.	510.	836.	1440.	1440.	1308.
1985	1440.	1440.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	1440.	1440.	2071.
1986	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	2890.	2890.	1799.
1987	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2548.
1988	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	510.	1401.
1989	642.	739.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1435.
1990	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
1991	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	2890.	2890.	1799.
1992	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	2890.	2890.	2791.
1993	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2548.
1994	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	2890.	2890.	1799.
1995	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	1440.	1440.	2548.
1996	1440.	1440.	510.	512.	510.	510.	510.	635.	745.	515.	1440.	1440.	846.
1997	1440.	1440.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	2890.	2890.	2556.
1998	2890.	2890.	3440.	3440.	3440.	3440.	510.	510.	682.	796.	1440.	1440.	2068.
1999	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	510.	1401.
2000	525.	510.	749.	672.	677.	882.	510.	510.	510.	553.	1440.	1440.	749.
2001	1440.	1440.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	1440.	1440.	2071.
2002	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
2003	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1557.
2004	1440.	1440.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	2890.	2890.	2042.
2005	2890.	2890.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	510.	510.	2150.
2006	526.	602.	878.	766.	839.	510.	510.	510.	510.	741.	551.	589.	628.
2007	920.	567.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	2890.	2890.	1931.
2008	2890.	2890.	1900.	1900.	1900.	1900.	510.	581.	511.	510.	1440.	1440.	1521.
2009	1440.	1440.	673.	783.	778.	510.	510.	510.	627.	893.	1440.	1440.	917.
2010	1440.	1440.	3440.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	1440.	1440.	2071.
2011	1440.	1440.	510.	510.	510.	510.	510.	510.	510.	538.	510.	583.	669.
2012	719.	860.	1900.	1900.	1900.	1900.	510.	510.	510.	517.	510.	510.	1020.
2013	642.	529.	538.	510.	582.	510.	510.	510.	539.	786.	1440.	1440.	712.
2014	1440.	1440.	511.	510.	822.	854.	1330.	1330.	1330.	1330.	1440.	1440.	1147.
2015	1440.	1440.	1900.	1900.	1900.	1900.	2050.	2050.	2050.	2050.	2890.	2890.	2042.
2016	2890.	2890.	3440.	3440.	3440.	3440.	2050.	2050.	2050.	2050.	2890.	2890.	2791.
2017	2890.	2890.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	1440.	1440.	1791.
MEAN	1605.	1618.	1933.	1949.	1969.	1955.	1288.	1292.	1295.	1312.	1594.	1597.	1616.

Frequency Analyses of Subsistence and Base Flow Targets and Shortages

Tables 8.13, 8.14, 8.17, and 8.18 compare statistical frequency metrics for instream flow targets and shortages in cfs developed from the monthly *SIM* and daily *SIMD* simulations. The *SIM/SIMD* simulation computations are performed with flow volumes in acre-feet. The simulation results quantities in acre-feet are converted to cfs using the *TABLES* CFS option. *SIMD* daily results are aggregated within *SIMD* to monthly quantities. The frequency metrics were computed with *TABLES* using the following set of input TIN file records.

```

2FRE  11   0   2   2   0   1
IDEN                      EFS-1                EFS-2
2FRE  12   0  -2   2   0   1
6FRE  11   0   2   2   0   1
IDEN                      EFS-1                EFS-2
6FRE  12   0  -2   2   0   1
    
```

Table 8.13
 Frequency Statistics for Subsistence and Base Flow
 Targets and Shortages for EFS-1 at Camer

	Targets (cfs)			Shortages (cfs)		
	<i>SIM</i>	<i>SIMD</i>	<i>SIMD</i>	<i>SIM</i>	<i>SIMD</i>	<i>SIMD</i>
	Monthly	Monthly	Daily	Monthly	Monthly	Daily
Mean	256.5	254.0	253.8	48.10	72.81	72.78
Stand Dev	192.4	194.0	194.7	91.51	82.37	123.9
Minimum	32.00	32.00	32.00	0.00	0.00	0.00
99.5%	32.00	32.00	32.00	0.00	0.00	0.00
99%	32.00	32.00	32.00	0.00	0.00	0.00
98%	32.00	32.00	32.00	0.00	0.00	0.00
95%	32.00	40.56	32.00	0.00	0.00	0.00
90%	39.32	56.72	32.00	0.00	0.00	0.00
85%	97.00	68.80	56.82	0.00	2.68	0.00
80%	140.0	88.92	110.0	0.00	7.29	0.00
75%	140.0	122.2	140.0	0.00	10.85	0.00
70%	160.0	160.0	160.0	0.00	14.91	0.00
60%	160.0	160.0	160.0	0.00	26.12	0.00
50%	190.0	190.0	190.0	0.00	46.22	0.00
40%	310.0	310.0	310.0	0.00	69.99	32.00
30%	310.0	310.0	310.0	32.00	94.33	55.87
25%	310.0	310.0	310.0	32.00	107.7	126.8
20%	330.0	330.0	330.0	112.0	127.5	160.0
15%	460.0	460.0	460.0	160.0	152.8	190.0
10%	460.0	460.0	460.0	172.7	181.4	276.7
5%	760.0	760.0	760.0	283.5	249.5	330.0
2%	760.0	760.0	760.0	330.0	322.9	432.5
1%	760.0	760.0	760.0	330.0	360.9	460.0
0.5%	760.0	760.0	760.0	377.2	391.6	760.0
Maximum	760.0	760.0	760.0	598.6	562.33	760.0

Table 8.14
 Frequency Statistics for Subsistence and Base Flow
 Targets and Shortages for EFS-2 at Hemp

	Targets (cfs)			Shortages (cfs)		
	<i>SIM</i>	<i>SIMD</i>	<i>SIMD</i>	<i>SIM</i>	<i>SIMD</i>	<i>SIMD</i>
	Monthly	Monthly	Daily	Monthly	Monthly	Daily
Mean	1,619	1,617	1,616	583.8	749.2	749.9
Stand Dev	855.4	853.8	856.7	721.3	613.7	786.1
Minimum	510.0	510.0	510.0	0.00	0.00	0.00
99.5%	510.0	510.0	510.0	0.00	0.00	0.00
99%	510.0	510.0	510.0	0.00	0.00	0.00
98%	510.0	510.0	510.0	0.00	0.00	0.00
95%	510.0	510.0	510.0	0.00	0.00	0.00
90%	510.0	510.0	510.0	0.00	11.70	0.00
85%	510.0	579.1	510.0	0.00	101.9	0.00
80%	638.4	706.6	510.0	0.00	195.2	0.00
75%	1,130	944.0	1,130	0.00	277.9	0.00
70%	1,330	1,330	1,330	0.00	360.4	0.00
60%	1,330	1,330	1,330	0.00	488.6	467.2
50%	1,440	1,440	1,440	387.1	510.0	510.0
40%	1,900	1,900	1,900	510.0	803.0	632.7
30%	1,900	1,900	1,900	830.4	1,107	1,330
25%	1,900	1,900	1,900	1,312	1,224	1,330
20%	2,050	2,050	2,050	1,330	1,329	1,440
15%	2,890	2,890	2,890	1,330	1,351	1,440
10%	2,890	2,890	2,890	1,440	1,507	1,900
5%	3,440	3,440	3,440	1,960	1,912	2,050
2%	3,440	3,440	3,440	2,493	2,247	2,774
1%	3,440	3,440	3,440	3,890	2,494	3,125
0.5%	3,440	3,440	3,440	3,409	2,802	3,440
Maximum	3,440	3,440	3,440	3,440	3,440	3,440

Tables 8.13 and 8.14 compare statistical frequency metrics for instream flow targets and shortages for water rights EFS-1 and EFS-2, respectively, for simulations that include all of the *HC* and *ES* records shown in Table 8.4 but exclude the *PF* records. The pulse flow component of the environmental flow standards are omitted here but added later in this chapter.

Methodologies for Determining Subsistence and Base Flow Targets

The hydrologic index for each month of the 1940-2017 hydrologic period-of-analysis is provided on a *HI* record in the hydrology input DSS file. The three conditions dry, average, and wet are represent on the *HI* record by the numbers 1, 2, and 3. The hydrologic condition defined by the *HC* record parameters is initially set at the beginning of January 1940 and updated at the beginning of March, July, and November of each year. The *ES* record flow limit quantities $ESQ(wr,es,m)$ are selected as a function of month (season) and hydrologic condition.

Determination of the base flow target in each *SIM* monthly or *SIMD* daily simulation time step consists of selecting the appropriate $ESQ(wr,es,m)$ read from the *ES* records. The $ESQ(wr,es,m)$ are specified by month on the *ES* records and are constant throughout each month. Referring to Table 8.4, the base flow target for water right IFS-1 at control point Camer in any month or day is either 110, 140, 97, 190, 310, 160, 460, 760, or 330 cfs. Likewise, the base flow target for IFS-2 at Hemp is either:

920 cfs (HC-1, winter), 1,130 cfs (HC-1, Spring), 950 cfs (HC-1, summer),
1,440 cfs (HC-2, winter), 1,900 cfs (HC-2, Spring), 1,330 cfs (HC-2, summer),
2,890 cfs (HC-3, winter), 3,440 cfs (HC-3, Spring), 2,050 cfs (HC-3, summer).

Subsistence flow $ESQ(wr,es,m)$ are also read from *ES* records. With SUBS entered for ESF in *ES* record field 2, the subsistence flow target is set equal to the appropriate $ESQ(wr,es,m)$ selected based on month (season) and hydrologic condition in the same manner as employed for the base flow targets discussed in the preceding paragraph. However, in the example, with SF50 entered for ESF in *ES* record field 2, the 50% rule described on page 201 is applied.

Regulated stream flows are computed within *SIM* or *SIMD* for each monthly or daily time step of the simulation. The targets set by the base flow $ESQ(wr,es,m)$ by themselves are not a function of regulated flow. However, the choice between subsistence flow and base flow $ESQ(wr,es,m)$ in each time step of the simulation is dependent upon the regulated flow. Also, with the 50% rule activated by $ESF=SF50$, the subsistence instream flow target is computed as a function of regulated flow. The rules followed by *SIM/SIMD* in combining the subsistence flow target and base flow target are outlined earlier in this chapter on pages 200-201.

Following the rules outlined on pages 200-201, base flow targets are applied differently depending on whether or not subsistence flow limits are specified on *ES* records. Subsistence flow targets are specified in this example for only hydrologic condition 1. With hydrologic condition 1 in effect, the base flow target is applied only if the regulated flow exceeds the base flow $ESQ(wr,es,m)$. With hydrologic condition 2 or 3 in effect and thus no subsistence flow $ESQ(wr,es,m)$ specified, the base flow limits are activated regardless of regulated flow.

Shortages occur if the instream flow targets are greater than the regulated stream flow. Shortages in meeting instream flow targets are computed as the target minus the regulated flow. In a monthly simulation, shortages are computed as monthly targets less monthly regulated flow. In a daily *SIMD* simulation, shortages are computed as daily targets less daily regulated flow, and monthly shortages are summations of daily shortages. Thus, the shortages for the *SIMD* versus *SIM* simulations are different. Shortages are discussed in more detail later in this chapter.

Daily regulated flows at a site may fluctuate greatly within a month. If only base flow targets are specified, monthly target flow rates in cfs are the same as daily targets in cfs since base flow targets by themselves are not a function of regulated flow. However, with both subsistence and base flow components, monthly and daily target flow rates are different due to regulated flow variability as discussed above. *SIM* monthly versus *SIMD* daily versus *SIMD* aggregated monthly daily shortages in meeting instream flow targets may vary greatly with highly variable daily regulated flows. The high flow pulse components of EFS covered in the next section are designed to preserve current regulated flows during selected high flow events and are conceptually and operationally very different than subsistence and base flow targets.

Modeling and Analysis of High Flow Pulse Standards

Chapter 6 of this manual describes *SIMD* capabilities for modeling pulse flow components of Senate Bill 3 (SB3) environmental flow standards (EFS). The variables entered on a *PF* record are defined in Chapter 4 of the *Users Manual*. The high flow pulse components of the EFS simulated by *IF* record water rights EFS-1 and EFS-2 at control points Camer and Hemp are defined in Tables 8.1 and 8.2 and modeled with the *PF* records in Table 8.4.

SB3 EFS include high flow pulse as well as subsistence and base flow components. Subsistence and base flow targets can be included in either a monthly *SIM* or daily *SIMD* simulation. Pulse flow *PF* records are employed to compute high flow pulse targets only in a daily *SIMD* simulation. The final instream flow targets for the example determined by *SIMD* for each day of the simulation consists of the larger of the *PF* record pulse flow targets and *ES* record subsistence and base flow targets.

Continuation of Frequency Analyses of Instream Flow Targets and Shortages

The frequency analysis metrics for water rights EFS-1 and EFS-2 at the Camer and Hemp control points tabulated in Tables 8.13 and 8.14 are for simulations with the pulse flow *PF* records omitted. Frequency analysis results for the final daily EFS-1 and EFS-2 instream flow targets and corresponding shortages for simulations with the *PF* records included are added in Tables 8.15 and 8.16. These statistics reflect alternative *SIMD* daily simulations with and without the *PF* records of Table 8.4. Without the *PF* records, the targets and shortages reflect the combined subsistence and base flow standards defined by the *ES* records and are labeled Sub&Base in Tables 8.15 and 8.16. The final combined instream flow targets computed by *SIMD* reflect subsistence, base, and pulse flow components of the flow standards as specified by the complete set of *HC*, *ES*, and *PF* records in Table 8.4 inserted in the DAT file of Table 7.3.

SIMD includes daily targets and shortages in the simulation results recorded in its SUB file and monthly aggregations of these quantities in its OUT file. The frequency analyses are performed using *TABLES* 2FRE and 6FRE records. The monthly means of the daily targets for the two alternative *SIMD* simulations are tabulated in Tables 8.11, 8.12, 8.20, and 8.21.

Frequency statistics compared in Tables 8.13, 8.14, 8.15, and 8.16 for simulated instream flow targets and shortages in cubic feet per second (cfs) include the mean and standard deviation and quantities equaled or exceeded during specified percentages of the 936 months or 28,490 days of the 1940-2017 hydrologic period-of-analysis.

Methodologies for Determining Pulse Flow Targets

By default, the instream flow target for an instream flow *IF* record water right in a particular day of a *SIMD* simulation is the maximum of the *PF* record pulse flow target versus the *ES* record subsistence and base flow target. In each day of the simulation, the *ES* record based subsistence and base flow target for a water right is computed first, followed by computation of the pulse flow target. *PF* record field 14 provides options for combining a *PF* record based target with the preceding *PF* record or *ES* record based target. The default option of adopting the maximum of the two consecutively computed targets is employed in the example.

Table 8.15
 Frequency Statistics for Targets and Shortages for EFS-1 at Camer for
 Daily *SIMD* Simulation With and Without *PF* Record High Flow Pulse Component

	Targets (cfs)				Shortages (cfs)			
	Sub&Base	Sub&Base	Final	Final	Sub&Base	Sub&Base	Final	Final
	Monthly	Daily	Monthly	Daily	Monthly	Daily	Monthly	Daily
Mean	254.0	253.8	374.7	375.5	72.81	72.78	72.81	72.78
Stand Dev	194.0	194.7	364.8	827.1	82.37	123.9	82.37	123.9
Minimum	32.00	32.00	32.00	32.00	0.00	0.00	0.00	0.00
99.5%	32.00	32.00	32.00	32.00	0.00	0.00	0.00	0.00
99%	32.00	32.00	32.00	32.00	0.00	0.00	0.00	0.00
98%	32.00	32.00	32.00	32.00	0.00	0.00	0.00	0.00
95%	40.56	32.00	40.66	32.00	0.00	0.00	0.00	0.00
90%	56.72	32.00	61.59	32.00	0.00	0.00	0.00	0.00
85%	68.80	56.82	81.89	56.90	2.68	0.00	2.68	0.00
80%	88.92	110.0	119.5	110.0	7.29	0.00	7.29	0.00
75%	122.2	140.0	160.0	140.0	10.85	0.00	10.85	0.00
70%	160.0	160.0	160.0	160.0	14.91	0.00	14.91	0.00
60%	160.0	160.0	190.0	160.0	26.12	0.00	26.12	0.00
50%	190.0	190.0	293.0	190.0	46.22	0.00	46.22	0.00
40%	310.0	310.0	317.1	310.0	69.99	32.00	69.99	32.00
30%	310.0	310.0	455.0	310.0	94.33	55.87	94.33	55.87
25%	310.0	310.0	460.0	330.0	107.7	126.8	107.5	126.8
20%	330.0	330.0	539.6	460.0	127.5	160.0	127.9	160.0
15%	460.0	460.0	742.7	460.0	152.8	190.0	152.8	190.0
10%	460.0	460.0	760.0	760.0	181.4	276.7	181.4	276.7
5%	760.0	760.0	1,186	760.0	249.5	330.0	249.5	330.0
2%	760.0	760.0	1,553	2,037	322.9	432.5	322.9	432.5
1%	760.0	760.0	1,886	3,649	360.9	460.0	360.9	460.0
0.5%	760.0	760.0	1,916	6,444	391.6	760.0	391.6	760.0
Maximum	760.0	760.0	2,080	21,086	562.3	760.0	562.3	760.0

The pulse flow variable (PFV) is the variable that is tracked and preserved in the pulse flow computations controlled by *PF* records. Alternative PFV choices selected in *PF* record field 2 are the regulated flow (default option 1), regulated stream flow excluding releases from upstream reservoirs (PFV = -1), or naturalized stream flow (PFV option 2). The default PFV option of regulated flow is adopted for all of the *PF* records in the example. The *PF* record target-setting computations are performed as the *IF* record water right (EFS-1 or EFS-2) is considered in the priority sequence. Thus, the regulated flow PFV is the regulated flow in the priority sequence at the priority of the specific *IF* record water right.

Regulated flow represents the actual flow at a site on a river reflecting all the premises and data incorporated in the *SIMD* model and thus is a logical choice for the PFV. Alternatively, adopting naturalized flows for the PFV allows natural condition environmental flows to be preserved in the simulation. The other option of regulated flows excluding upstream reservoir releases may also be a reasonable choice for PFV.

Table 8.16
 Frequency Statistics for Targets and Shortages for EFS-2 at Hemp for
 Daily *SIMD* Simulation With and Without *PF* Record High Flow Pulse Component

	Targets (cfs)				Shortages (cfs)			
	Sub&Base	Sub&Base	Final	Final	Sub&Base	Sub&Base	Final	Final
	Monthly	Daily	Monthly	Daily	Monthly	Daily	Monthly	Daily
Mean	1,617	1,616	1,725	1,723	749.2	749.9	749.2	749.9
Stand Dev	853.8	856.7	963.3	1,251	613.7	786.1	613.7	786.1
Minimum	510.0	510.0	510.0	510.0	0.00	0.00	0.00	0.00
99.5%	510.0	510.0	510.0	510.0	0.00	0.00	0.00	0.00
99%	510.0	510.0	510.0	510.0	0.00	0.00	0.00	0.00
98%	510.0	510.0	510.0	510.0	0.00	0.00	0.00	0.00
95%	510.0	510.0	510.0	510.0	0.00	0.00	0.00	0.00
90%	510.0	510.0	510.0	510.0	11.70	0.00	11.70	0.00
85%	579.1	510.0	587.5	510.0	101.9	0.00	101.9	0.00
80%	706.6	510.0	745.6	510.0	195.2	0.00	195.2	0.00
75%	944.0	1,130	1,130	1,130	277.9	0.00	277.9	0.00
70%	1,330	1,330	1,330	1,330	360.4	0.00	360.4	0.00
60%	1,330	1,330	1,440	1,330	488.6	467.2	488.6	467.2
50%	1,440	1,440	1,440	1,440	510.0	510.0	510.0	510.0
40%	1,900	1,900	1,900	1,900	803.0	632.7	803.0	632.7
30%	1,900	1,900	1,900	1,900	1,107	1,330	1,107	1,330
25%	1,900	1,900	2,050	2,050	1,224	1,330	1,224	1,330
20%	2,050	2,050	2,323	2,050	1,329	1,440	1,329	1,440
15%	2,890	2,890	2,890	2,890	1,351	1,440	1,351	1,440
10%	2,890	2,890	3,440	3,440	1,507	1,900	1,507	1,900
5%	3,440	3,440	3,440	3,440	1,912	2,050	1,912	2,050
2%	3,440	3,440	4,302	3,440	2,247	2,774	2,247	2,774
1%	3,440	3,440	4,320	5,720	2,494	3,125	2,494	3,125
0.5%	3,440	3,440	4,570	9,152	2,802	3,440	2,802	3,440
Maximum	3,440	3,440	4,990	16,800	3,440	3,440	3,440	3,440

High flow pulse targets are conceptually and operationally different than subsistence and base flow targets. Stream flow is extremely variable and large fluctuations in daily flows may occur within a particular month. The connections between simulated regulated stream flow (or other PFV variable) and *ES* record based subsistence and base flow targets are described earlier on page 212. The variations of subsistence and base flow targets with fluctuations in stream flow are relatively small compared to the variations of pulse flow targets determined totally as a function of stream flow rates. Pulse flow targets are set equal to or computed based directly on the regulated stream flows (or other PFV) that occur during each day of the high flow pulse event tracking period. The objective is to preserve selected high flow events.

Statistics for targets and shortages for a *SIMD* simulation without *PF* records (labeled Sub&Base) and a simulation with *PF* records (labeled Final) are presented in Tables 8.15 and 8.16. Seventy percent of the days of the simulation have targets of 160 cfs or less at control point Camer and 1,330 cfs or less at control point Hemp both with and without the *PF* records. The

targets are not affected by the *PF* records in about 70 percent of 28,490 days. The *PF* records increase the targets in about 30 percent of the days.

A *PF* record contains a set of requirements that are applicable for a particular season (months) and a particular hydrologic condition. The example includes nine *PF* records for each of the two instream flow water rights (EFS-1 and EFS-2) which reflect three seasons (winter, spring, summer) and three hydrologic conditions (HC1 dry, HC2 average, HC3 wet). Seasons are defined by *PF* record fields 9 and 10. The hydrologic condition specified in *PF* record 3 references the hydrologic conditions defined by the *HC* record. A single *HC* record defines hydrologic conditions for both the *ES* and *PF* records for a particular *IF* record water right. The optional identifier PFID in *PF* record field 17 labels the multiple *PF* records.

As explained in Chapter 6, a pulse event that has been initiated and is being tracked is said to be engaged. A pulse flow event is initiated if the regulated flow (or other PFV) exceeds the trigger and the initiation criteria listed for computational task 3 on pages 128-129 of Chapter 6 are satisfied. The daily pulse target is computed as the lesser of the regulated flow or the remaining volume to satisfy the total event volume criterion. The pulse event is terminated after setting a daily target if the total volume limit has been reached or the total number of days duration limit has been reached. Trigger, volume, duration, and frequency parameters are entered in *PF* record fields 4, 5, 6, and 7.

Pulse Flow Tables in the SIMD Daily Message SMM File

Any number of *PF* records for any number of water rights can be included in the tables for exploring pulse flow computations that are created in the SMM file by entries in *PF* record field 15 (column 64). The integer 3 in column 64 of the nine *PF* records for IFS-1 creates tabulations replicated here as Tables 8.17 and 8.18. The alternative SMM file table options that can be activated in *PF* record field 15 include:

1. pulse flow quantities within the water rights priority sequence illustrated by Table 8.17
2. summary of pulse event counts illustrated by Table 8.18,
3. both of the preceding tables illustrated by Tables 8.17 and 8.18
4. information available at the end of the water rights priority sequence for pulse days
5. information available at the end of the water rights priority sequence for all days
6. counts of pulse events initiated and terminated in each month.

Although the actual table created by *SIMD* in its SMM file covers the entire 1940-2017 period-of-analysis, Table 8.17 is terminated at March 2, 1941 for brevity. Each line represents a day of the simulation during which pulse flow events are engaged. The lines of daily quantities in the option 1 SMM file table illustrated by Table 8.17 are written as each water right is considered within the water rights priority sequence. Each line of relevant quantities in *PF* record field 15 options 4 and 5 tables are written at the end of the priority sequence. Regulated stream flow is a key quantity that changes as the simulation progresses through the water rights priority sequence. The quantities in Table 8.17 are discussed later in this chapter. *PF* record field 15 option 6 creates tables of detailed counts of pulse events which are summarized in the option 2 summary table replicated in Table 8.18. Table 8.18 provides counts of the number of pulse flow events initiated during the 1940-2017 simulation for each of the nine *PF* records and the number of these events that terminated without reaching the volume criterion.

Table 8.17
Beginning of PF Record Target Results Table from SMM File

Pulse Flow Target Computation Tracking Tabulation

Pulse flow variable (PFV), PFV cumulative volume, and target amounts are in acre-feet/day. Targets include targets from ES or other preceding records, the pulse flow target, and final adopted target. Pulse count is the number of pulse events during tracking period defined by PF record fields 8-11.

CP	Year	M	D	HC	ES Target	Pre-PF Target	PFV Flow	Pulse Flow	Pulse Volume	Pulse Count	Pulse Target	Final Target	WR and PF IDs
Camer	1940	2	4	1	218.2	218.2	4325.4	4325.4	4325.4	1	4325.4	4325.4	EFS-1 Winter,HC1,Camer
Camer	1940	2	5	1	218.2	218.2	4289.5	2354.6	8614.9	1	2354.6	2354.6	EFS-1 Winter,HC1,Camer
Camer	1940	4	7	1	277.7	277.7	9276.1	9276.1	9276.1	1	9276.1	9276.1	EFS-1 Spring,HC1,Camer
Camer	1940	4	8	1	277.7	277.7	1446.5	1446.5	10722.6	1	1446.5	1446.5	EFS-1 Spring,HC1,Camer
Camer	1940	4	9	1	277.7	277.7	697.5	697.5	11420.1	1	697.5	697.5	EFS-1 Spring,HC1,Camer
Camer	1940	4	10	1	277.7	277.7	3393.2	3393.2	14813.3	1	3393.2	3393.2	EFS-1 Spring,HC1,Camer
Camer	1940	4	11	1	277.7	277.7	1128.0	1128.0	15941.3	1	1128.0	1128.0	EFS-1 Spring,HC1,Camer
Camer	1940	4	12	1	277.7	277.7	1263.3	1263.3	17204.6	1	1263.3	1263.3	EFS-1 Spring,HC1,Camer
Camer	1940	4	13	1	277.7	277.7	1349.6	1349.6	18554.2	1	1349.6	1349.6	EFS-1 Spring,HC1,Camer
Camer	1940	4	14	1	277.7	277.7	474.7	474.7	19028.9	1	474.7	474.7	EFS-1 Spring,HC1,Camer
Camer	1940	4	15	1	277.7	277.7	474.4	474.4	19503.3	1	474.4	474.4	EFS-1 Spring,HC1,Camer
Camer	1940	4	16	1	277.7	277.7	3330.5	3330.5	22833.8	1	3330.5	3330.5	EFS-1 Spring,HC1,Camer
Camer	1940	4	17	1	277.7	277.7	962.8	962.8	23796.6	1	962.8	962.8	EFS-1 Spring,HC1,Camer
Camer	1940	4	18	1	277.7	277.7	492.0	103.4	24288.6	1	103.4	277.7	EFS-1 Spring,HC1,Camer
Camer	1940	7	1	2	317.4	317.4	88388.4	28600.0	88388.4	1	28600.0	28600.0	EFS-1 Summer,HC2,Camer
Camer	1940	7	2	2	317.4	317.4	53542.0	28600.0	53542.0	2	28600.0	28600.0	EFS-1 Summer,HC2,Camer
Camer	1940	7	3	2	317.4	317.4	25732.5	25732.5	25732.5	3	25732.5	25732.5	EFS-1 Summer,HC2,Camer
Camer	1940	7	4	2	317.4	317.4	42138.6	2867.5	67871.1	3	2867.5	2867.5	EFS-1 Summer,HC2,Camer
Camer	1940	11	1	3	912.4	912.4	5075.6	5075.6	5075.6	1	5075.6	5075.6	EFS-1 Winter,HC3,Camer
Camer	1940	11	2	3	912.4	912.4	972.1	972.1	6047.7	1	972.1	972.1	EFS-1 Winter,HC3,Camer
Camer	1940	11	3	3	912.4	912.4	1007.0	1007.0	7054.7	1	1007.0	1007.0	EFS-1 Winter,HC3,Camer
Camer	1940	11	4	3	912.4	912.4	155.1	155.1	7209.8	1	155.1	912.4	EFS-1 Winter,HC3,Camer
Camer	1940	11	5	3	912.4	912.4	0.0	0.0	7209.8	1	0.0	912.4	EFS-1 Winter,HC3,Camer
Camer	1940	11	6	3	912.4	912.4	0.0	0.0	7209.8	1	0.0	912.4	EFS-1 Winter,HC3,Camer
Camer	1940	11	7	3	912.4	912.4	0.0	0.0	7209.8	1	0.0	912.4	EFS-1 Winter,HC3,Camer
Camer	1940	11	8	3	912.4	912.4	0.0	0.0	7209.8	1	0.0	912.4	EFS-1 Winter,HC3,Camer
Camer	1940	11	9	3	912.4	912.4	0.0	0.0	7209.8	1	0.0	912.4	EFS-1 Winter,HC3,Camer
Camer	1940	11	10	3	912.4	912.4	0.0	0.0	7209.8	1	0.0	912.4	EFS-1 Winter,HC3,Camer
Camer	1940	11	23	3	912.4	912.4	7268.9	7268.9	7268.9	2	7268.9	7268.9	EFS-1 Winter,HC3,Camer
Camer	1940	11	24	3	912.4	912.4	19834.7	7631.1	27103.6	2	7631.1	7631.1	EFS-1 Winter,HC3,Camer
Camer	1941	3	1	3	1507.4	1507.4	17098.4	17098.4	17098.4	1	17098.4	17098.4	EFS-1 Spring,HC3,Camer
Camer	1941	3	2	3	1507.4	1507.4	17072.8	17072.8	34171.3	1	17072.8	17072.8	EFS-1 Spring,HC3,Camer
Camer	1941	3	3	3	1507.4	1507.4	15952.6	4228.7	50123.9	1	4228.7	4228.7	EFS-1 Spring,HC3,Camer

Table 8.18
Counts of Pulse Flow Events in SMM File

Counts of Pulse Flow Events and Events that Terminated Before Meeting Volume Criterion

CP	Events Initiated	Excess Initiated	Volume Failures	ID
Camer	16	0	2	Winter,HC1,Camer
Camer	100	0	9	Winter,HC2,Camer
Camer	33	0	3	Winter,HC3,Camer
Camer	15	0	6	Spring,HC1,Camer
Camer	93	0	16	Spring,HC2,Camer
Camer	40	0	1	Spring,HC3,Camer
Camer	19	0	19	Summer,HC1,Camer
Camer	107	0	96	Summer,HC2,Camer
Camer	36	0	30	Summer,HC3,Camer
Totals	459	0	182	

Counts for 9 PF records with option 2 or 3 selected in PF field 15.

Table 8.18 indicates that a total of 459 pulse events are initiated at the Cameron gage control point during the 1940-2017 simulation of which 182 events are terminated by other criteria before reaching their volume limit. No events in excess of the frequency criterion are counted since the excess events option is not activated by a *PO* record. Referring to Table 8.17, the first two of the 459 pulse flow events at control point Camer occur during February 4 and 5, 1940 and April 7-18, 1940. High pulse flow events on July 1-2, 1940, July 3, 1940, November 1-10, 1940, November 23-24, 1940, and March 1-3, 1941 are also tracked in Table 8.18.

Illustrative Examples of High Flow Pulse Events

Table 8.17 begins with the first engaged pulse flow event on February 4 and 5, 1940. Hydrologic condition 1 is in effect. The trigger, volume, and duration criteria from the *PF* record for winter and hydrologic condition 1 are 1,080 cfs (2,142 ac-ft/day), 6,680 acre-feet, and 8 days (Table 8.4). A base flow target of 218.2 acre-feet/day (110.0 cfs) was computed for each of these two days based on *ES* record specifications. The pulse event was terminated on February 5 due to meeting the total volume criterion of 6,680 acre-feet. The final targets tabulated in Table 8.17 for the two days are the pulse flow event are 4,325.4 and 8614.9 acre-feet/day, which sum to a two-day cumulative volume of 6,680 acre-feet. Two days is less than the duration limit criterion of 8 days, which means the volume criterion rather than duration criterion controlled termination.

The high flow pulse at control point Camer during April 7 through April 18, 1940 shown in Tables 8.17 and 8.19 is used here as another example to illustrate the characteristics of an engaged pulse in the *SIMD* simulation. The *IF*, *HC*, *ES*, and *PF* records in Table 8.4 define the environmental flow standards at the Cameron gage modeled in the WAM by water right EFS-1. Regulated flows are tabulated in both columns 3 and 6 and the final environmental flow standard (EFS) target is repeated in columns 5 and 7 in units of acre-feet/day and cubic feet per second, respectively. Table 8.19 includes the two days preceding the pulse event, the 12-day pulse event, and two days following the pulse event.

Naturalized flows are tabulated in columns 2 and 3 of Table 9.19 for comparison. The pulse event would be very different if naturalized flows (PFV option 2) was selected in PF record field 2 rather than regulated flows (default PFV option 1) for the flow variable used to define the pulse event. Either option may be reasonable and appropriate depending on circumstances.

April 7 through 18 is contained in the Spring season (March through June). Hydrologic condition (HC) one or 1.0 (dry) is read from the *HI* record for March 1940 and applied for the entire season. Subsistence (SF50) and base (BASE) flow limits for HC 1 for April of 32 cfs and 140 cfs are specified on the *ES* records in Table 8.4. These limits control before and after the pulse event and are over-ridden during the pulse event since the largest limit controls.

Hydrologic condition 1 Spring season trigger, volume, and duration parameters from the *PF* record are 3,200 cfs, 23,900 acre-feet, and 12 days. The pulse is initiated when the mean daily regulated flow equals or exceeds 3,200 cfs and continues until the total accumulated flow volume reaches 23,900 acre-feet or until the duration criterion of 12 days is reached, whichever occurs first. The pulse event is engaged, tracked, and terminated as follows.

- The regulated flow of 3,126 cfs on April 6 is less than the 3,200 cfs trigger. The regulated flow of 4,677 cfs on April 7 exceeds the trigger and initiates the pulse event.
- The cumulative flow volume starting on April 7 is tabulated in column 4 of Table 8.19. The cumulative volume limit of 23,900 acre-feet is reached on April 18. The pulse flow target on April 18 is 103 acre-feet computed as 24,289 acre-feet minus 23,900 acre-feet. The target of 103 acre-feet/day converts to 51.9 cfs, which is less than the base flow limit of 140 cfs. The base flow limit controls on April 18. The pulse was terminated by the cumulative volume criteria but would have been terminated at the end of April 18 by the 12 day duration criterion if the cumulative volume limit had not been reached.
- The pulse flow target is set equal to the regulated flow each day from April 7 through April 17 as shown in columns 6 and 7 of Table 8.19.

Table 8.19
High Pulse Flow Event at Control Point Camer During April 7 through April 18, 1940

1 Date	2 Naturalized Flow (acre-feet)	3 Regulated Flow (acre-feet)	4 Pulse Volume (acre-feet)	5 EFS Target (acre-feet)	6 Regulated Flow (cfs)	7 EFS Target (cfs)
April 5, 1940	139.9	0.00	-	63.47	0.00	32.00
April 6, 1940	6,451	6,201	-	277.7	3,126	140.0
April 7, 1940	7,672	9,276	9,276	9,276	4,677	4,677
April 8, 1940	8,147	1,447	10,723	1,447	729.3	729.3
April 9, 1940	7,798	697.5	11,420	697.5	351.6	351.6
April 10, 1940	6,946	3,393	14,813	3,393	1,711	1,711
April 11, 1940	2,853	1,128	15,941	1,128	568.7	568.7
April 12, 1940	3,280	1,263	17,205	1,263	636.9	636.9
April 13, 1940	3,059	1,350	18,554	1,350	680.4	680.4
April 14, 1940	2,625	474.7	19,029	474.7	239.3	239.3
April 15, 1940	2,192	474.4	19,503	474.4	239.2	239.2
April 16, 1940	1,678	3,331	22,834	3,331	1,679	1,679
April 17, 1940	1,007	962.8	23,797	962.8	485.4	485.4
April 18, 1940	589.4	492.0	24,289	277.7	248.0	140.0
April 19, 1940	397.6	1,159	-	277.7	584.5	140.0
April 20, 1940	303.7	2,419	-	277.7	1,219	140.0

Water right targets including *IF* record instream flow targets are computed in the *SIMD* simulation within the water rights priority sequence. Regulated flows change as water rights are considered in priority order. The example in this chapter is simplified by instream flow rights EFS-1 and EFS-2 having priority numbers of 999999 making them the most junior rights in the WAM. The regulated flows used to set the instream flow targets are the final regulated flows. Therefore, the option controlled by *PF* record field 12 discussed in the next paragraph is not relevant. However, regulated flow changes generally complicate pulse flow target computations.

The default *PF* record field 12 option 1 is to use within-priority-sequence regulated flow for initiating a pulse but to use an end-of-priority-sequence accumulated regulated flow volume adjustment in applying the volume accumulation termination criterion. *PF* record field 12 option 2 consists of using within-priority-sequence regulated flow for both the pulse flow event initiation and termination criteria. With either option, the pulse flow targets will not necessarily be the same as the regulated flows, unless the instream flow rights are the most junior rights in the model, which is the case in the example.

Control point Hemp is the river system outlet. The largest diversion right in the DAT file is a diversion at Hemp that is supplied by releases from four reservoirs of which three are located upstream of Camer. Thus, regulated flows at Camer include releases from upstream reservoirs for downstream diversions as well as being affected by storage in upstream reservoirs. As already noted, both water rights EFS-1 and EFS-2 at Camer and Hemp have priorities of 999999 which are junior to all other water rights. However, other reasonable modeling strategies could include assigning flood control operations priorities that are senior to all other rights including all instream flow rights, which could affect the pulse flow targets. Regulated flows and pulse flow targets are already affected by senior rights due to routing of flow changes from current through future days in the simulation.

Multiple Instream Flow Rights at the Same Control Point

The two environmental flow standards are modeled with the input records of Table 8.4 by two *IF* record rights with water right identifiers EFS-1 and EFS-2. *IF* record instream flow right EFS-1 is located at control point Camer. Instream flow right EFS-2 is located at control point Hemp. Each *IF* record right includes subsistence, base, and high flow pulse components.

An alternative variation of the input records of Table 8.4 is presented in Table 8.20. The only difference is that pulse flows are modeled as separate water rights rather than being combined with subsistence and base flows in the same water right. New rights PF-1 and PF-2 are created by transferring the *PF* records from rights EFS-1 and EFS-2. The new *IF* record instream flow rights PF-1 and PF-2 each include a required *ES* record with ESF option PFES in *ES* record field 2. The same hydrologic condition *HC* record is repeated for all four *IF* record water rights in this example. *SIMD* allows each water right to have different *HC* record parameters.

Water rights are considered in priority order in the simulation computations. With two or more *IF* record rights at the same control point (Table 8.20), the target for a junior right is combined with the target from the preceding senior right as specified by IFM(IF,2) in *IF* record field 7. With pulse flow *PF* and subsistence/base flow *ES* records for the same *IF* record right (Table 8.4), the instream flow targets are combined as specified in *PF* record field 14. The options for combining consecutive targets are as follows.

<i>IF</i> record field 7	<i>PF</i> record field 14	Method for combining junior and senior targets.
1 (default)	1	The junior target replaces the senior target.
2	2 (default)	The largest target is adopted.
3	3	The smallest target is adopted.
–	4	The two targets are added together

Table 8.20
 DAT File Input Records for Two *IF* Record Water Rights at Each of Two Control Points

```

**      1      2      3      4      5      6      7      8      9      10
**345678901234567890123456789012345678901234567890123456789012345678901234
**-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!
IF Camer      -9.          999999          EFS-1
HC Hemp      1 HI      0 M      J      N      0.0      1.5      2.5      -9.
ES SF501     32.      32.      32.      32.      32.      32.      32.      32.      32.      32.
ES BASE1     110.     110.     140.     140.     140.     140.     97.     97.     97.     110.     110.
ES BASE2     190.     190.     310.     310.     310.     310.     160.    160.    160.    160.    190.    190.
ES BASE3     460.     460.     760.     760.     760.     760.     330.    330.    330.    330.    460.    460.
**
IF Camer      -9.          999999      2          PF-1
HC Hemp      1 HI      0 M      J      N      0.0      1.5      2.5      -9.
ES PFES
PF  1 1      1080.    6680.    8 1 0 11 2 0 0 2 0 3      Winter,HC1,Camer
PF  1 2      1080.    6680.    8 3 0 11 2 0 0 2 0 3      Winter,HC2,Camer
PF  1 3      2140.   14900.   10 2 0 11 2 0 0 2 0 3      Winter,HC3,Camer
PF  1 1      3200.   23900.   12 1 0 3 6 0 0 2 0 3      Spring,HC1,Camer
PF  1 2      3200.   23900.   12 3 0 3 6 0 0 2 0 3      Spring,HC2,Camer
PF  1 3      4790.   38400.   14 2 0 3 6 0 0 2 0 3      Spring,HC3,Camer
PF  1 1      560.    28600.    6 1 0 7 10 0 0 2 0 3      Summer,HC1,Camer
PF  1 2      560.    28600.    6 3 0 7 10 0 0 2 0 3      Summer,HC2,Camer
PF  1 3      990.    55500.    8 2 0 7 10 0 0 2 0 3      Summer,HC3,Camer
**
**-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!
IF Hemp      -9.          999999          EFS-2
HC Hemp      1 HI      0 M      J      N      0.0      1.5      2.5      -9.
ES SF501     510.     510.     510.     510.     510.     510.     510.    510.    510.    510.    510.
ES BASE1     920.     920.     1130.    1130.    1130.    1130.     950.    950.    950.    950.    920.    920.
ES BASE2    1440.    1440.    1900.    1900.    1900.    1900.   1330.   1330.   1330.   1330.   1440.   1440.
ES BASE3    2890.    2890.    3440.    3440.    3440.    3440.   2050.   2050.   2050.   2050.   2890.   2890.
**
IF Hemp      -9.          999999      2          EFS-2
HC Hemp      1 HI      0 M      J      N      0.0      1.5      2.5      -9.
ES PFES
PF  1 1      5720.   49800.    8 1 0 11 2 0 0 2 0 0      Winter,HC-1,Hemp
PF  1 2      5720.   49800.    8 3 0 11 2 0 0 2 0 0      Winter,HC-2,Hemp
PF  1 3     11200.  125000.   10 2 0 11 2 0 0 2 0 0      Winter,HC-3,Hemp
PF  1 1     85300.  23900.   13 1 0 3 6 0 0 2 0 0      Spring,HC-1,Hemp
PF  1 2     85300.  23900.   13 3 0 3 6 0 0 2 0 0      Spring,HC-2,Hemp
PF  1 3     16800.  38400.   19 2 0 3 6 0 0 2 0 0      Spring,HC-3,Hemp
PF  1 1     2620.   17000.    7 1 0 7 10 0 0 2 0 0      Summer,HC-1,Hemp
PF  1 2     2620.   17000.    7 3 0 7 10 0 0 2 0 0      Summer,HC-2,Hemp
PF  1 3     5090.   40900.    9 2 0 7 10 0 0 2 0 0      Summer,HC-3,Hemp
**-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!-----!

```

The environmental flows standards are modeled with the input records of Table 8.4 with only one *IF* record water right at each of the two control points. *IF* record field 7 is blank since the input parameter IFM(IF,2) is not relevant. With a blank *PF* record field 14, the default option 2 of adopting the largest target is employed. The environmental flows standards are modeled with the input records of Table 8.20 with two *IF* record water rights at each of the two control points. IFM(IF,2) option 2 selected in *IF* record field 7 adopts the largest of alternative targets.

The main reason for using different *IF* record rights to model pulse flow versus subsistence and base flow components of an environmental flow standard is to increase output flexibility. Separate output records are generated for each individual water right in the *SIMD* simulation results output files.

The 43 simulation result variables that can be included in the *SIM* or *SIMD* output DSS file as monthly and/or daily time series quantities are listed on page 47 of the *Users Manual*. Five of these variables are listed in the first column of Table 8.21. These same simulation results variables can be tabulated as either monthly (type 2, OUT file) or daily (type 6, SUB file) quantities in a *TABLES* output TOU file using the time series input records listed in the second column of Table 8.21. All *HEC-DSSVue* features including frequency analysis options can be applied to any or all of the simulation results variables. *TABLES* 2FRE (monthly) and 6FRE (daily) frequency analysis routines can be applied to some of the simulation results variables.

Table 8.21
Instream Flow Targets and Shortages in *SIM* and *SIMD* Simulation Results

Variables Selected on <i>OF</i> Records for Inclusion in <i>SIM/SIMD</i> DSS File	<i>TABLES</i> Time Series Records	<i>TABLES</i> Frequency 2FRE and 6FRE Records
<u>Instream Flow Targets and Shortages for Control Points</u>		
15. IFT instream flow target	2IFT and 6IFT	8 instream flow target
16. IFS instream flow target shortage	2IFS and 6IFS	9 instream flow shortage
<u>Instream Flow Targets and Shortages for <i>IF</i> Record Water Rights</u>		
27. TIF instream flow target	2TIF and 6TIF	
28. IFT combined instream flow target	2IFT and 6IFT	11 instream flow target
29. IFS shortage for combined target	2IFS and 6IFS	12 instream flow shortage

Instream flow targets (IFT) and instream flow target shortages (IFS) can be recorded by *SIMD* in its DSS (monthly and daily), OUT (monthly), and SUB (daily) output files for either control points or *IF* record water rights. If only one *IF* record right is located at a particular control point, the IFT target is the same for the water right and control point. If two or more *IF* record rights are located at the same control point, the IFT target for the control point is the IFT target for the most junior (last computed) water right at the control point after multiple-right combining operations have been completed.

If only one *IF* record instream flow right is located at a particular control point, the TIF target and IFT target for the single water right are the same. TIF and IFT targets are different only if two or more *IF* record rights are located at the same control point. The TIF target is the instream flow target for an individual *IF* record water right before or without combining with other rights at the control point. The TIF target is the instream flow target after multiple-right combining operations are performed.

Monthly *SIM* instream flow targets or monthly summations of *SIMD* daily instream flow targets at control points Camer and Hemp are tabulated in the tables listed in Table 8.22. The third column of Table 8.22 indicates with the shortages are applicable to just the water right (WR) in the third column, just the control point (CP) in the second column, or are the same for both the water right and control point (WR/CP). The monthly subsistence and base flow targets in Tables 8.9 and 8.10 were computed in a *SIM* monthly simulation. The instream flow targets in the other tables are monthly summations from a *SIMD* daily simulation.

Table 8.22
 Tables of *SIM* and/or *SIMD* Monthly Instream Flow Targets Tabulated with *TABLES*

Table	Control Point	Water Right	Variable	TABLES Record	Description of the Quantities Tabulated in the Table
8.9	Camer	EFS-1	IFT-WR/CP	2IFT	<i>SIM</i> monthly subsistence and base flow targets.
8.10	Hemp	EFS-2	IFT-WR/CP	2IFT	<i>SIM</i> monthly subsistence and base flow targets.
8.11	Camer	EFS-1	IFT-WR/CP	2IFT	<i>SIMD</i> summations of <i>daily</i> subsistence/base.
8.12	Hemp	EFS-2	IFT-WR/CP	2IFT	<i>SIMD</i> summations of <i>daily</i> subsistence/base.
8.23	Camer	PF-1	TIF-WR	2TIF	<i>SIMD</i> monthly summations of <i>daily</i> PF targets.
8.24	Hemp	PF-2	TIF-WR	2TIF	<i>SIMD</i> monthly summations of <i>daily</i> PF targets.
8.27	Camer	EFS-1	IFT-WR/CP	2IFT	Final <i>SIMD</i> targets in <i>SIM</i> input dataset.
8.28	Hemp	EFS-1	IFT-WR/CP	2IFT	Final <i>SIMD</i> targets in <i>SIM</i> input dataset.

Table 8.23
 High Pulse Flow Targets (cfs) for Water Right PF-1 at Control Point Camer

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.	116.	0.	402.	0.	0.	1395.	0.	0.	0.	372.	0.	191.
1941	0.	0.	1249.	0.	0.	0.	1238.	0.	0.	0.	0.	0.	211.
1942	0.	0.	0.	1205.	0.	0.	0.	391.	0.	0.	501.	0.	173.
1943	0.	0.	389.	402.	0.	0.	431.	0.	0.	0.	0.	0.	103.
1944	109.	0.	1166.	0.	0.	0.	404.	0.	0.	0.	337.	0.	170.
1945	0.	0.	1249.	0.	0.	0.	400.	0.	0.	0.	98.	217.	167.
1946	0.	0.	1249.	0.	0.	0.	557.	40.	0.	0.	501.	0.	198.
1947	0.	0.	1166.	0.	0.	0.	428.	0.	0.	0.	168.	0.	149.
1948	0.	116.	0.	174.	430.	16.	185.	67.	2.	0.	112.	0.	92.
1949	0.	0.	250.	821.	0.	0.	0.	0.	0.	0.	0.	0.	89.
1950	0.	361.	0.	667.	399.	0.	212.	0.	473.	0.	0.	0.	173.
1951	0.	0.	0.	0.	0.	348.	0.	0.	41.	0.	0.	0.	32.
1952	0.	0.	0.	339.	61.	0.	54.	0.	0.	0.	0.	109.	47.
1953	0.	0.	0.	223.	26.	0.	167.	0.	0.	0.	225.	109.	62.
1954	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	112.	0.	9.
1955	0.	0.	0.	402.	0.	0.	192.	0.	0.	0.	0.	0.	49.
1956	0.	116.	0.	0.	389.	0.	0.	0.	0.	0.	112.	0.	51.
1957	0.	0.	389.	0.	0.	0.	0.	309.	99.	0.	501.	0.	109.
1958	0.	0.	1249.	0.	0.	0.	259.	226.	0.	0.	0.	0.	147.
1959	0.	241.	0.	402.	187.	402.	346.	122.	42.	0.	337.	0.	171.
1960	0.	0.	0.	131.	219.	0.	112.	0.	164.	0.	337.	0.	80.
1961	0.	0.	625.	0.	0.	645.	1208.	0.	0.	0.	337.	0.	236.
1962	0.	0.	0.	346.	255.	595.	196.	65.	481.	0.	337.	0.	188.
1963	0.	0.	0.	0.	0.	0.	131.	0.	0.	0.	0.	63.	16.
1964	0.	0.	389.	0.	0.	0.	34.	0.	0.	0.	337.	0.	64.
1965	0.	0.	204.	811.	55.	0.	388.	0.	0.	0.	337.	0.	149.
1966	0.	0.	389.	803.	0.	0.	564.	0.	0.	0.	0.	0.	147.
1967	0.	0.	0.	0.	389.	0.	149.	0.	0.	0.	337.	0.	73.
1968	0.	0.	1249.	0.	0.	0.	1787.	0.	0.	0.	189.	302.	299.
1969	0.	0.	625.	645.	0.	0.	357.	0.	0.	0.	0.	326.	164.
1970	0.	0.	1166.	0.	0.	0.	511.	0.	0.	0.	0.	0.	142.
1971	0.	0.	0.	0.	0.	0.	172.	0.	0.	0.	169.	109.	38.
1972	0.	0.	0.	0.	389.	377.	384.	0.	0.	0.	218.	109.	124.
1973	0.	0.	777.	402.	0.	0.	771.	0.	0.	0.	501.	0.	206.
1974	0.	0.	0.	0.	777.	0.	296.	0.	0.	0.	501.	0.	132.
1975	0.	0.	0.	1017.	0.	0.	971.	0.	0.	0.	0.	0.	166.
1976	0.	0.	0.	402.	0.	0.	1371.	0.	0.	0.	250.	242.	191.
1977	0.	0.	625.	645.	0.	0.	563.	0.	0.	0.	0.	0.	154.
1978	0.	113.	0.	0.	0.	0.	168.	0.	0.	0.	0.	43.	27.

1979	66.	0.	1166.	0.	0.	0.	1163.	0.	0.	0.	0.	0.	203.
1980	109.	116.	389.	0.	777.	0.	512.	0.	0.	0.	0.	0.	161.
1981	0.	0.	389.	0.	0.	0.	613.	235.	0.	0.	250.	0.	126.
1982	0.	0.	0.	402.	777.	0.	0.	0.	0.	0.	0.	0.	99.
1983	0.	361.	926.	55.	0.	0.	671.	0.	0.	0.	0.	0.	168.
1984	0.	0.	0.	0.	0.	0.	0.	0.	0.	198.	112.	217.	45.
1985	0.	0.	625.	0.	0.	645.	85.	0.	94.	0.	337.	0.	149.
1986	0.	0.	0.	0.	667.	402.	351.	112.	481.	0.	501.	0.	210.
1987	0.	0.	625.	0.	625.	0.	830.	0.	0.	0.	218.	109.	204.
1988	0.	0.	0.	0.	0.	1205.	449.	0.	0.	0.	112.	0.	146.
1989	0.	0.	389.	0.	777.	0.	0.	0.	0.	0.	0.	0.	99.
1990	0.	0.	389.	803.	0.	0.	0.	77.	234.	0.	112.	0.	134.
1991	217.	0.	0.	803.	389.	0.	39.	190.	36.	0.	406.	0.	173.
1992	0.	0.	1249.	0.	0.	0.	1019.	0.	0.	0.	246.	242.	233.
1993	0.	0.	1249.	0.	0.	0.	443.	0.	0.	0.	0.	68.	149.
1994	0.	241.	0.	0.	1034.	0.	193.	216.	0.	0.	0.	485.	182.
1995	0.	0.	1249.	0.	0.	0.	719.	0.	0.	0.	0.	0.	167.
1996	0.	0.	0.	0.	0.	0.	208.	0.	0.	0.	156.	175.	45.
1997	0.	0.	1249.	0.	0.	0.	1715.	0.	0.	0.	0.	485.	293.
1998	0.	0.	1249.	0.	0.	0.	230.	0.	0.	0.	337.	0.	153.
1999	0.	0.	389.	0.	389.	0.	1040.	0.	0.	0.	112.	0.	164.
2000	0.	0.	0.	381.	0.	0.	56.	0.	0.	0.	337.	0.	64.
2001	0.	0.	1249.	0.	0.	0.	778.	0.	0.	0.	337.	0.	200.
2002	0.	0.	0.	0.	0.	0.	1271.	0.	0.	0.	337.	0.	136.
2003	0.	0.	777.	0.	0.	0.	1078.	0.	0.	0.	0.	0.	158.
2004	217.	116.	0.	1205.	0.	0.	863.	0.	0.	0.	501.	0.	241.
2005	0.	0.	1249.	0.	0.	0.	827.	0.	0.	0.	112.	0.	186.
2006	0.	0.	0.	402.	0.	0.	209.	0.	0.	0.	0.	109.	60.
2007	0.	0.	1166.	0.	0.	0.	1805.	0.	0.	0.	0.	0.	252.
2008	0.	0.	0.	0.	1166.	0.	225.	0.	0.	0.	89.	0.	125.
2009	0.	0.	0.	377.	0.	0.	158.	0.	0.	0.	337.	0.	72.
2010	0.	0.	1249.	0.	0.	0.	176.	139.	0.	0.	0.	0.	133.
2011	215.	0.	0.	0.	0.	0.	174.	0.	0.	0.	0.	0.	33.
2012	109.	0.	1166.	0.	0.	0.	332.	0.	0.	0.	0.	0.	137.
2013	109.	0.	0.	0.	0.	0.	192.	0.	0.	0.	337.	0.	53.
2014	0.	0.	0.	0.	223.	0.	252.	0.	254.	0.	199.	1.	78.
2015	109.	0.	1055.	17.	0.	0.	1061.	0.	0.	0.	501.	0.	231.
2016	0.	0.	0.	1291.	0.	0.	500.	0.	0.	0.	250.	242.	190.
2017	0.	0.	0.	402.	0.	0.	228.	262.	0.	0.	0.	326.	102.
MEAN	16.	24.	434.	210.	133.	59.	473.	31.	31.	3.	173.	52.	138.

Table 8.24
High Pulse Flow Targets (cfs) for Water Right PF-2 at Control Point Hemp

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.	0.	0.	0.	0.	0.	254.	0.	0.	0.	1120.	0.	114.
1941	0.	0.	1084.	0.	0.	0.	997.	0.	0.	0.	2574.	0.	388.
1942	0.	0.	0.	0.	0.	0.	0.	0.	577.	0.	0.	0.	47.
1943	0.	0.	0.	0.	0.	0.	0.	0.	0.	188.	0.	0.	16.
1944	502.	0.	0.	0.	1166.	0.	0.	0.	457.	0.	812.	0.	246.
1945	0.	0.	1154.	0.	0.	0.	697.	0.	0.	0.	0.	1218.	261.
1946	0.	0.	1084.	0.	0.	0.	0.	0.	524.	0.	2093.	0.	307.
1947	0.	0.	0.	0.	0.	0.	0.	254.	0.	0.	0.	435.	58.
1948	0.	499.	0.	0.	0.	0.	390.	0.	0.	0.	0.	0.	71.
1949	0.	409.	0.	0.	0.	0.	172.	0.	208.	167.	740.	0.	138.
1950	808.	773.	0.	0.	0.	0.	254.	144.	0.	0.	0.	0.	162.
1951	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1952	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	519.	254.	64.
1953	0.	0.	0.	0.	0.	0.	169.	0.	0.	0.	526.	804.	126.
1954	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1955	0.	514.	0.	0.	0.	0.	0.	0.	87.	0.	0.	0.	47.
1956	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1957	0.	613.	0.	402.	0.	0.	808.	0.	0.	0.	3021.	0.	397.
1958	0.	0.	1084.	0.	0.	0.	657.	0.	0.	0.	0.	0.	148.
1959	0.	947.	0.	0.	0.	0.	360.	0.	0.	85.	1334.	369.	251.
1960	0.	0.	0.	0.	0.	0.	384.	0.	0.	0.	1093.	0.	122.
1961	0.	0.	1195.	0.	0.	0.	435.	0.	0.	0.	953.	932.	296.

1962	0.	0.	0.	0.	0.	0.	169.	90.	0.	0.	381.	1342.	167.
1963	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1964	0.	0.	0.	0.	0.	0.	0.	0.	234.	0.	1418.	0.	136.
1965	0.	0.	0.	0.	1166.	0.	0.	0.	251.	258.	1309.	0.	249.
1966	0.	0.	0.	1205.	0.	0.	0.	338.	0.	0.	0.	0.	128.
1967	0.	0.	0.	0.	0.	0.	125.	0.	0.	0.	1732.	0.	153.
1968	0.	0.	1134.	0.	0.	0.	328.	0.	0.	0.	373.	2492.	367.
1969	0.	0.	1157.	0.	0.	0.	0.	0.	157.	0.	0.	1572.	245.
1970	0.	0.	0.	0.	0.	0.	0.	0.	569.	0.	495.	0.	87.
1971	0.	0.	0.	0.	0.	0.	169.	0.	0.	0.	796.	1091.	172.
1972	0.	0.	0.	0.	0.	0.	0.	346.	0.	169.	1665.	0.	181.
1973	0.	0.	0.	0.	0.	0.	454.	0.	0.	612.	1056.	1000.	262.
1974	1084.	0.	0.	0.	0.	0.	0.	238.	87.	0.	1139.	0.	213.
1975	0.	0.	0.	1120.	0.	0.	657.	0.	0.	0.	0.	0.	148.
1976	0.	0.	0.	0.	0.	0.	423.	0.	0.	0.	0.	2939.	285.
1977	0.	0.	1095.	0.	0.	0.	0.	0.	0.	0.	0.	0.	93.
1978	0.	838.	0.	0.	0.	0.	0.	169.	0.	0.	0.	0.	79.
1979	529.	0.	0.	0.	0.	0.	1024.	0.	0.	0.	0.	0.	132.
1980	1365.	0.	0.	0.	0.	0.	0.	0.	0.	338.	0.	0.	145.
1981	0.	0.	0.	0.	0.	402.	555.	0.	0.	0.	0.	0.	80.
1982	0.	0.	0.	0.	0.	0.	328.	0.	0.	0.	0.	783.	94.
1983	0.	1021.	0.	0.	0.	0.	0.	414.	191.	0.	0.	0.	129.
1984	0.	0.	0.	0.	0.	0.	0.	0.	0.	239.	680.	0.	76.
1985	0.	0.	1114.	0.	0.	0.	0.	0.	0.	254.	925.	0.	192.
1986	0.	0.	0.	0.	0.	0.	0.	0.	349.	0.	1493.	1855.	309.
1987	0.	0.	1084.	0.	0.	0.	465.	0.	0.	0.	0.	722.	193.
1988	528.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	45.
1989	369.	237.	0.	0.	0.	0.	0.	338.	0.	0.	0.	0.	78.
1990	0.	439.	0.	803.	0.	0.	0.	0.	304.	132.	0.	0.	136.
1991	738.	0.	0.	0.	0.	0.	0.	425.	0.	0.	814.	477.	206.
1992	0.	0.	1084.	0.	0.	0.	873.	0.	0.	0.	0.	2876.	410.
1993	0.	0.	1084.	0.	0.	0.	493.	0.	0.	0.	0.	0.	134.
1994	0.	934.	185.	0.	0.	0.	0.	0.	0.	473.	0.	1806.	281.
1995	0.	0.	1084.	0.	0.	0.	0.	495.	0.	0.	0.	737.	197.
1996	0.	0.	0.	0.	0.	0.	0.	169.	0.	0.	572.	1317.	173.
1997	0.	0.	1084.	0.	0.	0.	328.	0.	0.	0.	0.	1743.	268.
1998	0.	0.	1084.	0.	0.	0.	0.	0.	87.	0.	1686.	0.	238.
1999	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2000	0.	0.	0.	0.	0.	0.	0.	0.	0.	202.	763.	0.	80.
2001	0.	0.	1084.	0.	0.	0.	142.	0.	175.	0.	940.	0.	196.
2002	0.	0.	0.	0.	0.	0.	486.	0.	0.	0.	637.	0.	94.
2003	0.	0.	0.	0.	0.	0.	0.	0.	227.	301.	0.	0.	44.
2004	1783.	187.	0.	0.	0.	0.	328.	0.	0.	0.	1968.	0.	355.
2005	0.	0.	1084.	0.	0.	0.	0.	254.	0.	0.	0.	0.	114.
2006	0.	0.	0.	0.	0.	0.	0.	0.	0.	169.	0.	369.	46.
2007	185.	0.	777.	0.	0.	0.	328.	0.	0.	0.	0.	0.	110.
2008	0.	0.	0.	0.	0.	0.	0.	98.	0.	0.	250.	0.	29.
2009	0.	0.	0.	0.	0.	0.	0.	0.	87.	0.	1369.	0.	120.
2010	0.	0.	1084.	0.	0.	0.	0.	0.	262.	0.	0.	0.	114.
2011	607.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	52.
2012	576.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	49.
2013	369.	0.	0.	0.	0.	0.	0.	0.	175.	0.	763.	0.	108.
2014	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	766.	0.	63.
2015	1571.	0.	0.	0.	1166.	0.	657.	0.	0.	0.	1867.	0.	442.
2016	0.	0.	0.	1184.	0.	0.	0.	1084.	0.	0.	0.	0.	189.
2017	1684.	2134.	0.	0.	0.	0.	0.	254.	0.	0.	0.	1351.	443.
MEAN	163.	122.	267.	60.	45.	5.	178.	65.	64.	46.	521.	365.	159.

Combined *ES* record subsistence and base flow targets (IFT or TIF) without *PF* record pulse flow targets are tabulated in Tables 8.9, 8.10, 8.11, and 8.12. *PF* records are not read by *SIM* (Tables 8.9, 8.10) and were omitted in the *SIMD* simulation (Tables 8.11 and 8.12). The TIF target quantities for water rights PF-1 and PF-2 in Tables 8.21 and 8.22 are from a simulation with the *SIMD* DAT file records listed in Table 8.20. The IFT targets in Tables 8.xx and 8.xx are monthly summations of the final daily targets with all components activated, which are same with either the Table 8.4 or 8.20 dataset. The final daily targets are the largest of the subsistence and base targets versus pulse flow targets in each day. Daily, not monthly, targets are combined.

The *PF* record pulse flow targets are compared with the *ES* record combined subsistence and base flow targets in Table 8.25 and Figures 8.1, 8.2, 8.3, and 8.4. In each of the 28,490 days of the 1940-2017 simulation, the final combined instream flow target is set as the larger of the subsistence/base flow target and the pulse flow target. At control point Camer, the average of the daily subsistence/base flow targets is 253.8 cfs, the pulse flow targets average 137.7 cfs, and the final combined targets have a mean of 375.5 cfs as shown in Table 8.25. The corresponding means of the targets at control point Hemp are 1,616 cfs, 158.7 cfs, and 1,734 cfs.

The frequency metrics in Table 8.25 and the time series plots of Figures 8.1, 8.2, 8.3, and 8.4 illustrate the great differences in the characteristics of pulse flows versus subsistence and base flows. The relatively infrequent high pulse events are characterized by large fluctuations over short periods of time and flow targets of zero in most days. The subsistence/base targets are much less variable with targets never dropping below 32 cfs at Camer and 510 cfs at Hemp. The daily targets are compared in Figures 8.1 and 8.3. The 936 monthly means of the 28,490 daily targets are compared in Tables 8.2 and 8.4. Monthly averaging of daily targets greatly reduces variability. Monthly means of high flow pulse targets are much smaller than daily means.

Table 8.25
Frequency Statistics for EFS Target Components

	EFS-1 TIF	PF-1 TIF	Camer IFT-CP	EFS-2 TIF	PF-2 TIF	Hemp IFT-CP
mean (cfs)	253.8	137.7	375.5	1,616	158.7	1,734
std dev (cfs)	194.7	842.3	827.0	856.7	1,125	1,251
<u>Targets in cfs with Specified Exceedance Frequencies</u>						
maximum	760.0	21,086	21,086	3,440	16,800	16,800
0.1%	760.0	11,511	11,511	3,440	16,800	16,800
0.2%	760.0	9,360	9,360	3,440	12,050	12,050
0.5%	760.0	6,444	6,444	3,440	9,151	9,151
1%	760.0	3,649	3,649	3,440	5,720	5,720
2%	760.0	2,036	2,036	3,440	2,620	3,440
5%	760.0	760.0	760.0	3,440	0.0	3,440
10%	460.0	760.0	760.0	2,890	0.0	3,440
15%	460.0	460.0	460.0	2,890	0.0	2,890
20%	330.0	460.0	460.0	2,050	0.0	2,050
30%	310.0	310.0	310.0	1,900	0.0	1,900
40%	310.0	310.0	310.0	1,900	0.0	1,900
50%	190.0	190.0	190.0	1,440	0.0	1,440
60%	160.0	160.0	160.0	1,330	0.0	1,330
70%	160.0	160.0	160.0	1,330	0.0	1,330
80%	110.0	110.0	110.0	510.0	0.0	510.0
85%	56.8	57.0	57.0	510.0	0.0	510.0
90%	32.0	32.0	32.0	510.0	0.0	510.0
minimum	32.0	32.0	32.0	510.0	0.0	510.0

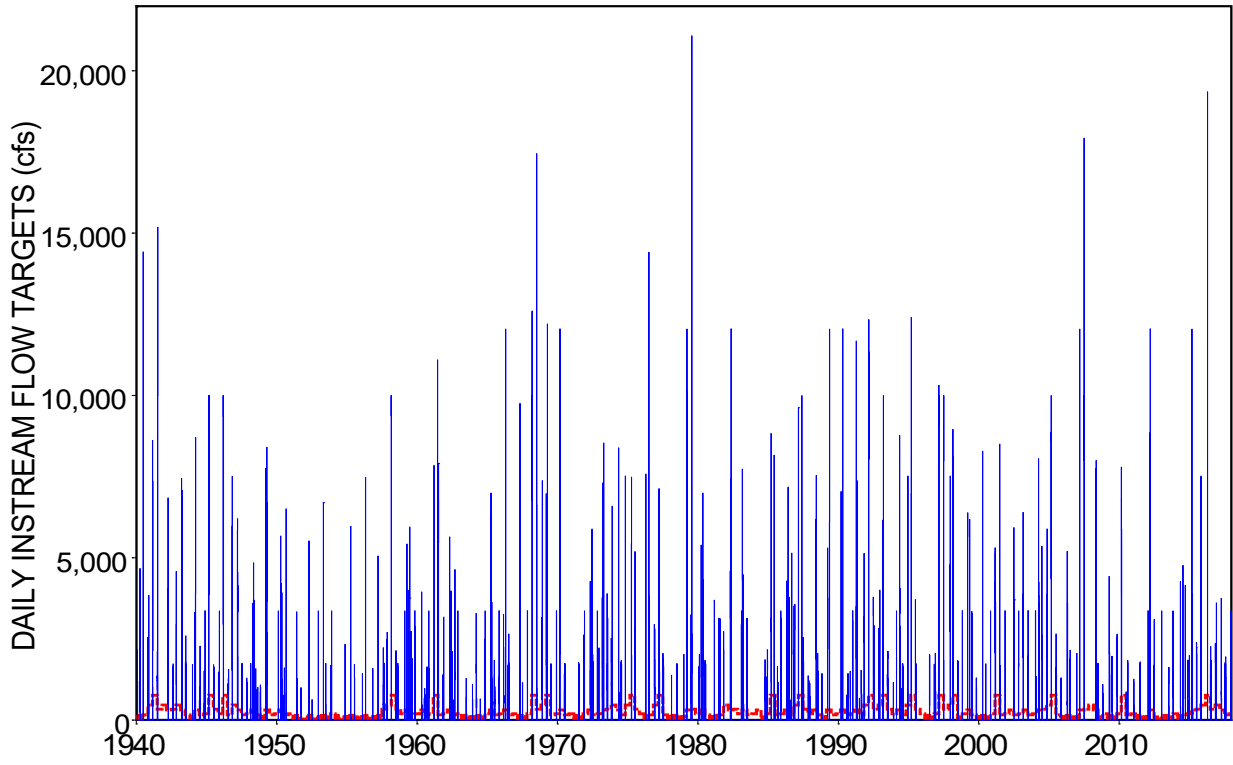


Figure 8.1 Daily Subsidence/Base Flow Targets (red dashed line) and Pulse Flow Targets (blue solid line) at Control Point Camer

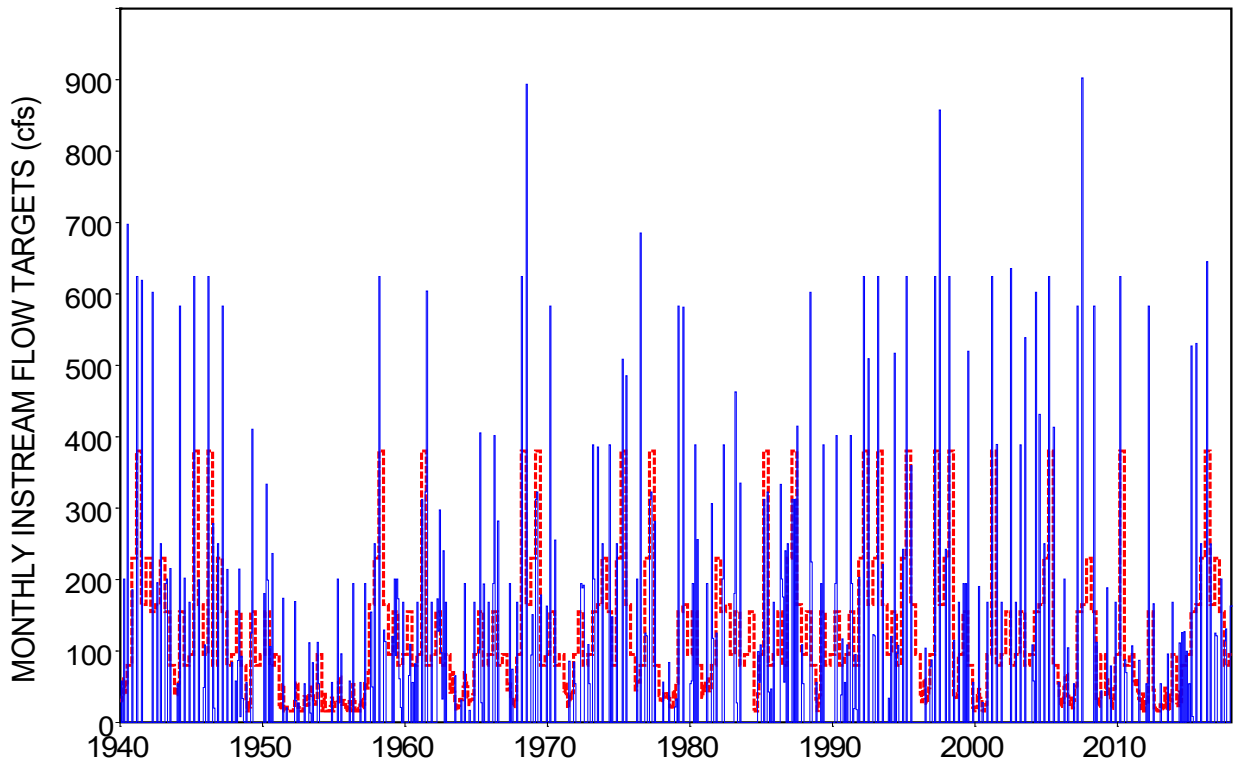


Figure 8.1 Monthly Means of Daily Subsidence/Base Flow Targets (red dashed line) and Pulse Flow Targets (blue solid line) at Control Point Camer

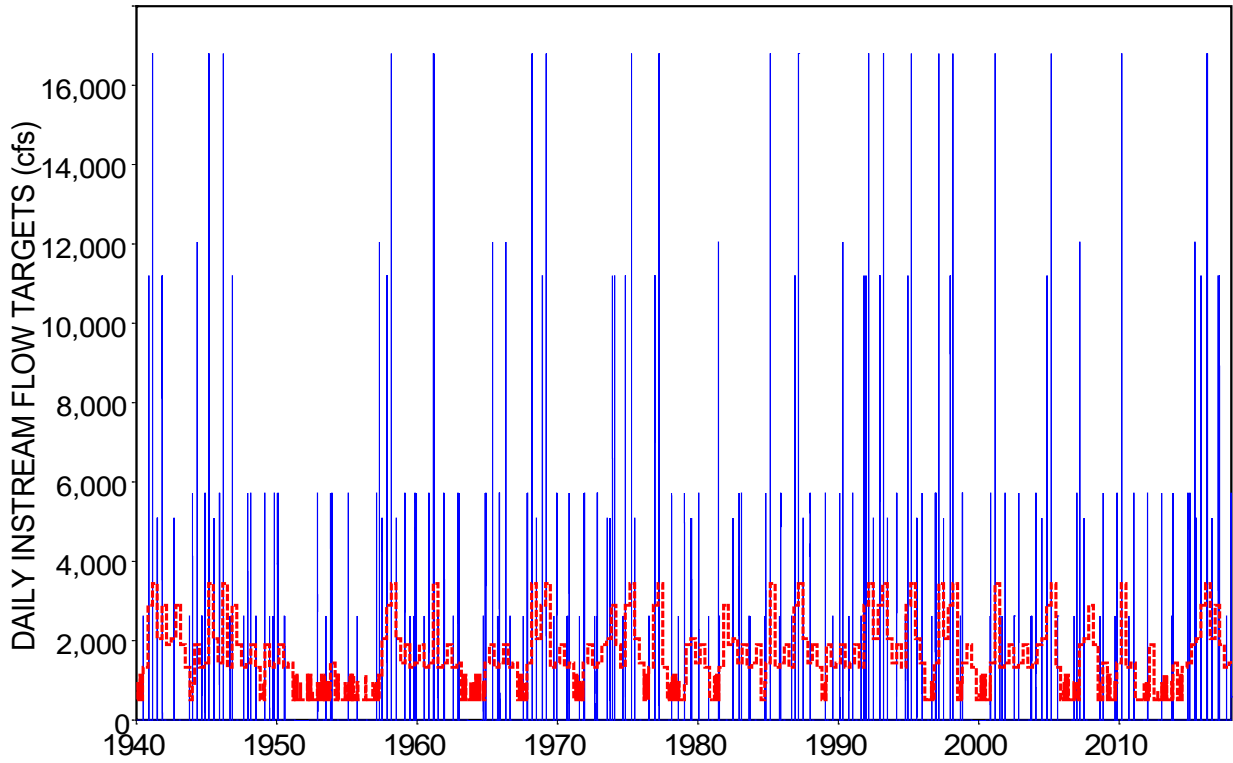


Figure 8.3 Daily Subsidence/Base Flow Targets (red dashed line) and Pulse Flow Targets (blue solid line) at Control Point Hemp

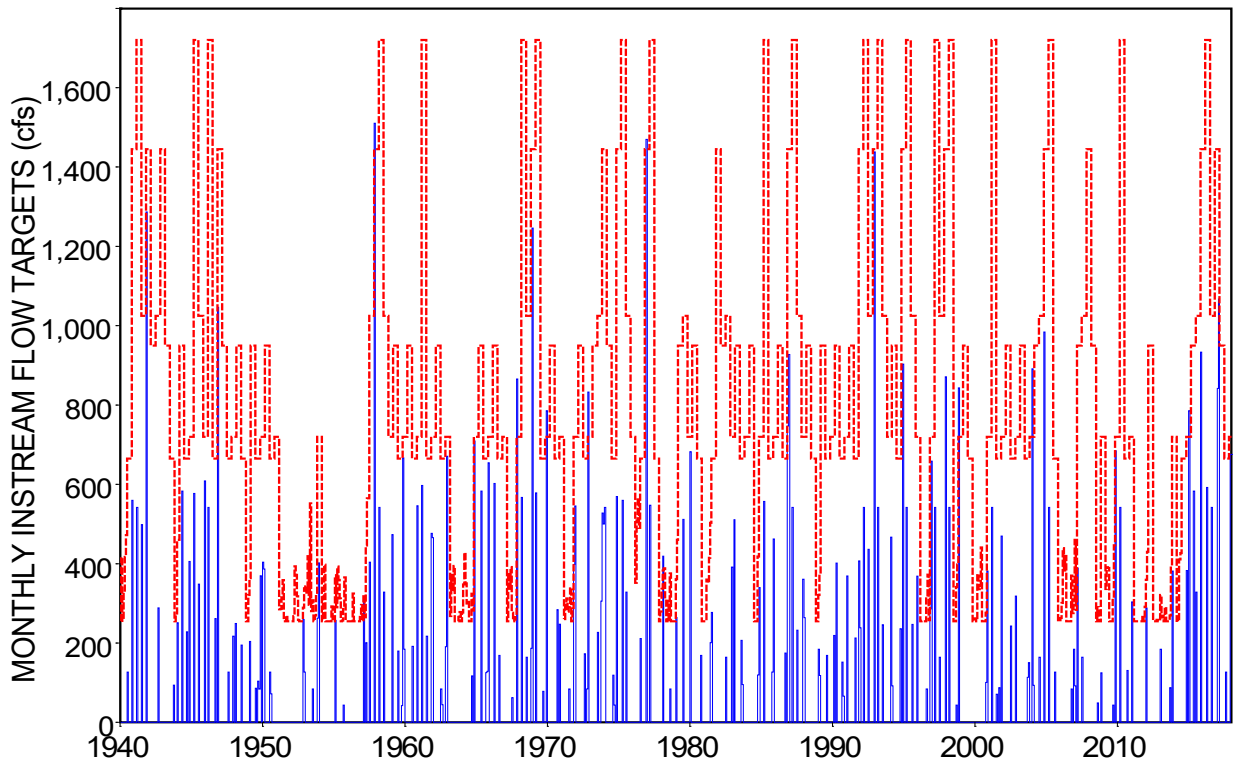


Figure 8.4 Monthly Means of Daily Subsidence/Base Flow Targets (red dashed line) and Pulse Flow Targets (blue solid line) at Control Point Hemp

Computation of Instream Flow Shortages

Instream flow shortages are defined as the difference between targets and regulated flows in those days in which regulated flow is less than the target. The example has shortages in meeting *ES* record subsistence and base flow targets as is to be expected but incurs no shortages in meeting *PF* record pulse flow targets. The lack of pulse flow shortages is due to the instream flow rights being the most junior rights in the model. In general, pulse flow targets can experience shortages as explained in the next paragraph.

Pulse flow targets are set based on replicating regulated flows for each of the days during which a pulse flow event is engaged. Target setting computations are performed within the water right priority sequence based on the regulated flow in effect at the priority of the *IF* record instream flow right. Regulated flows at a control point change in the water rights priority sequence due to stream flow depletions for diversions and refilling reservoir storage, return flows, and releases from upstream reservoirs. Thus, the pulse flow targets set based on regulated flows in the priority sequence are not necessarily the same as the regulated flows at the completion of the priority sequence, unless the *IF* record instream flow right is the most junior in the WAM. Shortages in meeting instream flow targets are based on regulated flows at the completion of the priority-sequenced water rights simulation computations.

Monthly or daily minimum instream flow limits (targets) in acre-feet are computed within the *SIM* and *SIMD* simulation as specified by *IF*, *HC*, *ES*, *PF*, and other input records as described in the preceding sections of this chapter. The shortages in acre-feet in meeting the minimum stream flow volume limits are computed as the difference between the targeted minimum flow limits and simulated regulated flows during those periods (days or months) during which the regulated flow volume is less than the limits. Shortages represent failures in meeting the targets. The following discussion deals with certain aspects of targets and shortages.

Shortages in achieving minimum instream flow targets are computed based on Equation 8.1, where *IFS* denotes instream shortage, *IFT* denotes instream flow target, *RF* denotes regulated stream flow, and the subscript *t* denotes daily or monthly time period.

$$\begin{aligned} \text{IFS}_t &= \text{IFT}_t - \text{RF}_t && \text{for } \text{IFT}_t > \text{RF}_t \\ \text{and } \text{IFS}_t &= 0.0 && \text{otherwise} \end{aligned} \tag{Eq. 8.1}$$

As noted in the preceding section of this chapter, multiple water rights can be located at the same control point. Instream flow targets (*IFT*) and shortages (*IFS*) are recorded in the output files for either individual instream flow *IF* record water rights or control points. The input parameter *IFM*(*if*,2) in *IF* record field 7 sets the option for combining multiple instream flow rights at the same control point. With the default *IFM*(*if*,2) option 1 (blank *IF* record field 7), the junior target replaces the more senior preceding target. Options 2 and 3 consist of adopting the largest (option 2) or the smallest (option 3) target. The targets for individual water rights are computed and recorded as each *IF* water right is considered in the priority sequence. The *IFT* for a control point for the current time step is recorded in the output files at the completion of the priority sequenced simulation computations. A similar option in *PF* record field 14 is applicable for the different situation in which high pulse flow *EFS* components are combined with other *EFS* components within the same single *IF* record water right.

Stream flow at a control point is affected by reservoir storage and releases, diversions, and return flows at upstream control points. Thus, regulated flows (RF) change as each water right is considered in turn in the water rights priority loop simulation computations. Targets for individual instream flow rights are computed within the priority sequence at the priority of the *IF* record water rights. Shortages are computed using Equation 8.1 at the completion of the water rights sequence using the final regulated flow for the current time step.

Either a monthly or daily simulation proceeds in the same manner as follows. Targets for each instream flow right are computed as the individual water rights are considered in priority order in the simulation computations. Shortages are computed at the completion of the priority sequence based on Equation 8.1, where IFT is the target computed at the appropriate priority and RF_t is the final regulated flow at the completion of the water rights priority sequence. The IFT output for each water right is computed in the priority sequence at the water right's priority. The IFT recorded in the output files for a control point is the final target at the completion of the priority sequence. If only one *IF* input record water right is located at a particular control point, the instream flow target and shortage volumes recorded in the output DSS, OUT, and/or SUB output files for the control point are identically the same as the target output for the water right.

OUT and SUB files include instream flow targets and shortages for individual rights and targets for control points. OUT and SUB output files do not include instream flow shortages for control points. Shortages for control points are computed within the *TABLES* time series tabulation and frequency analysis routines using Equation 8.1 with targets and regulated flows read from an OUT or SUB file. Shortages are computed the same with the same results, but managed a little differently for DSS output versus the output stored in OUT and SUB files.

OF record options allow a daily simulation to include monthly summations along with daily quantities in the simulation results output files. As discussed in the following paragraphs, total monthly shortages from a daily simulation differ with different approaches to monthly summations of daily quantities. Monthly summations of daily instream flow shortages output for control points are different than shortages output for water rights. The two definitions of monthly shortage volumes computed as summations of daily volumes expressed below are not the same.

$$\text{Monthly Shortages} = \sum (IFT_{\text{day}} - RF_{\text{day}}) \neq \text{Monthly Shortages} = \sum (IFT_{\text{day}}) - (\sum RF_{\text{day}})$$

SUB (daily), OUT (monthly), and DSS (daily and monthly) output files from a daily *SIMD* simulation include both daily and monthly quantities. Reservoir storage volumes are end-of-day and end-of-month volumes in acre-feet. Monthly flow volumes are the summation of daily flow volumes in acre-feet. The monthly instream flow targets and shortages for individual rights from a daily simulation are computed within *SIMD* by summing daily quantities.

$$IFT_{\text{month}} = \sum IFT_{\text{day}} \quad \text{and} \quad IFS_{\text{month}} = \sum IFS_{\text{day}}$$

For a daily *SIMD* simulation generating monthly output along with daily output, the monthly instream flow shortages for control points are different than the shortages for water rights. Monthly shortages for water rights are the summation of daily shortages as noted above. Monthly shortages for control points are the summation of daily targets less monthly regulated flows.

$$IFS_{\text{month}} = (\sum IFS_{\text{day}}) - RF_{\text{month}} \quad \text{where} \quad RF_{\text{month}} = \sum RF_{\text{day}}$$

Organization of SIM/SIMD Simulation Results

Options for selecting and organizing the time series of simulation results to be recorded in the DSS, OUT, SUB, and SOU output files are summarized in this section. The 43 variables output by *SIM* and *SIMD* are listed on page 47 of the *Users Manual* with the *OF* record description and defined in Chapter 5 of the *Reference Manual*. The simulation results variables are also described on pages 196-199 of the *Users Manual* in conjunction with the *TABLES* time series records. *SIM* generates monthly quantities for the 42 time series variables which it stores in DSS, OUT, and/or SOU output files as described in *Reference Manual* Chapter 5. The OUT file is replaced with a CRM file for conditional reliability modeling (CRM) as explained in *Reference Manual* Chapter 8. A daily *SIMD* simulation produces daily values and/or aggregated (flow volume summation or end-of-month storage volume) monthly totals for the 42 time series variables which it stores in DSS (daily and monthly), SUB (daily), OUT (monthly), and/or SOU (monthly) files. The present Chapter 8 and the following discussion highlight four of the 43 simulation results variables: instream flow targets (IFT) and shortages (IFS) in meeting instream flow targets for two water rights (EFS-1 and EFS-2) and two control points (Camer and Hemp).

Results from either a monthly or daily simulation may be extremely massive. Each hydrologic period-of-analysis daily time series has about $365/12=30.4$ times more quantities than the corresponding monthly time series. The size and complexity of the output files and execution time may be reduced by recording only selected data in the output files. The options for selecting data to be included in the output files do not affect the actual simulation computations.

Input Options Controlling Selection of Results to Include in Output Files

The selection of simulation results to include in the output files is organized by the model user employing the following two sets of options.

1. Control points, water rights, and reservoirs (reservoir/hydropower projects) to be included in the output files are selected using input parameters on the *JD*, *JT*, *CO*, *C2*, *WO*, *W2*, *G2*, *GO*, *RO*, and *R2* records as explained in Chapters 3 and 4 of the *Users Manual*. The same selected control points, water rights, and reservoirs are included in the DSS, OUT, CRM, SUB, and SOU files and other auxiliary files.
2. Either daily and/or monthly quantities for any or all of the 43 variables can be selected for inclusion in the *SIM* or *SIMD* DSS output file using options controlled by the *OF* record. Monthly quantities can be included in the SOU file. *OF* record variable selection options are not applicable for the OUT, SUB, or other files.

SIM simulation results are written to the DSS, OUT, CRM, SOU, and SUB 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, and (3) reservoir/hydropower project (reservoir) output records. *JD* record fields 5 and 6 in combination with *WO*, *GO*, *CO*, and *RO* records are used to specify which water rights, control points, and reservoirs have monthly quantities included in the output files. 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 along with corresponding monthly totals. *JT* record fields 2 and 3 in combination with *W2*, *G2*, *C2*, and *R3*

records control which water rights, control points, and reservoirs have daily quantities included in the output files. For a daily *SIMD* simulation, the specifications controlling selection of water rights, control points, and reservoirs for daily results are also applied to the monthly results.

The series of simulation results cover the entire hydrologic period-of-analysis for a monthly *SIM* simulation and by default also for a daily *SIMD* simulation. However, options on the *JT* records allow the results recorded in the output files for a *SIMD* simulation to be limited to a specified sub-period of the hydrologic period-of-analysis.

The OUT and SUB files contain all of the 43 variables for each of the selected water rights, control points, and reservoirs. Options on the *OF* record allow user selection of all or any subset of the 43 variables to be included in the daily and monthly quantities in the DSS output file. All or a fixed default subset of the 43 variables can be included in the monthly SOU file. File options for the DSS and SOU files are controlled by the *OF* record, as explained on pages 45-47 in Chapter 3 of the *Users Manual*. All of the input parameters on the *OF* record are applicable to both *SIM* and *SIMD* simulations, though *OF* record field 4 input parameter DSS(3) options 2 and 3 apply only to a daily simulation.

Examples of Input Records Controlling Output Options

The records of the *SIMD* input DAT file of Table 7.3 relevant to the present discussion are copied below.

JD	77	1940	1	0	0	7	20						
OF	1	0	2										Examples
JT	1	2	0	0	0	0	0	2	2	2	2		

OUTCP2 and OUTWR2 options 1 and 2 in *JT* record fields 2 and 3 result in the output files containing output records for all control points and all water rights. These options are applied to both monthly and daily simulation results in a daily *SIMD* simulation. Both monthly and daily output are controlled by daily specifications in a daily simulation. However, since *SIM* skips over all daily-only *SIMD* records including the *JT* record, the corresponding OUTCP and OUTWR options in *JD* record fields 5 and 6 are employed for a *SIM* simulation. The option 2 entries in *JT* record fields 9, 10, 11, and 12 activated the message SMM file tables discussed in Chapter 7.

DSS(3) option 2 in *OF* record field 4 activates the DSS output file and records of both daily and monthly quantities in the DSS file. The one for DSS(1) in *OF* record field 2 activates the OUT file. Without an *OF* record or with an *OF* record with blank (or zero) field 2, the OUT file is automatically created by *SIM* and *SIMD*. The SUB file is automatically created by *SIMD* if daily output is specified.

The DAT file input records can be revised as follows to reduce the size of the output files. With the following input records, water right output records are recorded in the output files for only water rights EFS-1 and EFS-2 and control point output records are created only for control points Camer and Hemp. Although all input parameter fields of the *JT* record are now blank, the *JT* record is still required to activate the daily *SIMD* simulation. The *WO* and *CO* records are relevant only in a monthly simulation. With no entries for OUTWR and OUTCP on the *JD* record and no entries for OUTWR2 and OUTCP2 on the *JT* record, water rights and control points for inclusion in *SIMD* output are selected only by the *W2* and *C2* records.

JD	77	1940		1		0		0			7		20
JT	0	0	0	0	0	0	0	0	0	0			
JU	0	0	0	2	2								
WO				EFS-1				EFS-2					
CO		Camer		Hemp									
W2				EFS-1				EFS-2					
C2		Camer		Hemp									
OF	1	0	2	4									
OF	15	16	28	29									

Examples

An auxiliary *OF* record variable list follows the initial *OF* record if and only if DSS(4) in field 5 is a positive non-zero integer. As already discussed, *SIM/SIMD* simulation results include time series of the variables listed on page 47 of the *Users Manual*. With a DSS and/or SOU file activated by DSS(2) or DSS(3), the default DSS(4) (blank *OF* record field 5) results in the default lists of control point, water right, and reservoir simulation results variables listed on page 47 being included in the output. A DSS(4) of -1 results in all of the variables being included in the DSS and SOU files. The second *OF* record allows DSS(4) output variables to be included in the DSS file. The following DSS(4)=4 variables are selected by the *OF* record shown above.

- 15 – instream flow targets (IFT) for specified control points
- 16 – instream flow shortages (IFS) for specified control points
- 28 – instream flow targets (IFT) for specified water rights
- 29 – instream flow shortages (IFS) for specified water rights

The DSS file created by the DAT file input records listed above is discussed in the next section. The DSS file contains IFT and IFS output records for water rights EFS-1 and EFS-2 and control points Camer and Hemp.

The OUT (monthly) and SUB (daily) files are designed to be read by the WRAP program *TABLES*. DSS files are read by *HEC-DSSVue*. *SIM* and *SIMD* create a DSS output file directly. *TABLES* also includes options for reading *SIM* and *SIMD* simulation results from OUT and SUB files, manipulating the data, and writing the revised data to a DSS file. *TABLES* capabilities are explained in Chapter 7 of the *Reference Manual* and Chapter 5 of the *Users Manual*. *HEC-DSSVue* capabilities are briefly described in Chapter 6 of the *WRAP Users Manual* and documented in detail in the *HEC-DSSVue User's Manual* available at the Hydrologic Engineering Center (HEC) website along with the *HEC-DSSVue* software

The SOU file is a text file created by *SIM* or *SIMD* that contains monthly time series data tabulated in a column format that can be viewed with any text editor such as Microsoft *WordPad* or *NotePad* or read by Microsoft *Excel* and converted to a spreadsheet. *TABLES* also includes options to similarly create a text file (TOU file) with the time series data tabulated in columns. *HEC-DSSVue* also include options for tabulating the time series data as columns and directly converting the data to a Microsoft Excel spreadsheet.

The present discussion focuses on simulation results for instream flow *IF* record water rights and control points. Simulation results for reservoirs are organized similarly. Reservoir output includes data associated with hydroelectric power plants as well as reservoirs. Although the variables differ, simulation results for *IF* input record water rights and *WR* input record water rights are managed similarly.

Managing Simulation Results with HEC-DSSVue

The Hydrologic Engineering Center (HEC) Data Storage System (DSS) and the *HEC-DSSVue* user interface component of the DSS are designed for conveniently and efficiently storing, organizing, managing, and analyzing time series datasets, including extremely large datasets. The small dataset discussed here illustrates basic *HEC-DSSVue* features. Execution of *SIMD* with the example dataset, including the simulation results output specifications noted on the preceding page, results in creation of a DSS output file of DSS records containing the selected simulation results. The DSS file is accessed with *HEC-DSSVue*. The main screen of *HEC-DSSVue* replicated as Figure 8.5 lists the 16 DSS records contained in the DSS file.

The screenshot shows the HEC-DSSVue main window with the following components:

- File Name:** C:\WRAP\AAA - Daily Examples\DailyCh8.dss
- Pathnames Shown:** 16, **Pathnames Selected:** 680, **Pathnames in File:** 680, **File Size:** 1.4 MB
- Search A:** (Dropdown menu)
- By Parts:** (Dropdown menu)
- Part C Search Menu:** A dropdown menu is open, showing options: IFS-CP, IFS-WR, IFT-CP, and IFT-WR.
- Table:** A table with 16 rows and 6 columns (Number, Part A, Part B, Part C, Part E, Part F).
- Log/Output Area:** A text area at the bottom containing file paths for each record.
- Buttons:** Select, De-Select, Clear Selections, Restore Selections, Set Time Window.
- Status Bar:** No time window set.

Number	Part A	Part B	Part C	Part E	Part F
1	DAILYCH8	CAMER	IFS-CP	1MON	CP
2	DAILYCH8	CAMER	IFS-CP	1DAY	CP DAILY
3	DAILYCH8	CAMER	IFS-WR	1DAY	EFS-1
4	DAILYCH8	CAMER	IFS-WR	1MON	EFS-1
5	DAILYCH8	CAMER	IFT-CP	1MON	CP
6	DAILYCH8	CAMER	IFT-CP	1DAY	CP DAILY
7	DAILYCH8	CAMER	IFT-WR	1DAY	EFS-1
8	DAILYCH8	CAMER	IFT-WR	1MON	EFS-1
9	DAILYCH8	HEMP	IFS-CP	1MON	CP
10	DAILYCH8	HEMP	IFS-CP	1DAY	CP DAILY
11	DAILYCH8	HEMP	IFS-WR	1DAY	EFS-2
12	DAILYCH8	HEMP	IFS-WR	1MON	EFS-2
13	DAILYCH8	HEMP	IFT-CP	1MON	CP
14	DAILYCH8	HEMP	IFT-CP	1DAY	CP DAILY
15	DAILYCH8	HEMP	IFT-WR	1DAY	EFS-2
16	DAILYCH8	HEMP	IFT-WR	1MON	EFS-2

Log/Output Area:

```

/DAILYCH8/CAMER/IFS-CP/31Jan1940 - 31Dec2016/1MON/CP/
/DAILYCH8/CAMER/IFS-CP/01Jan1940 - 31Dec2016/1DAY/CP DAILY/
/DAILYCH8/CAMER/IFS-WR/01Jan1940 - 31Dec2016/1DAY/EFS-1/
/DAILYCH8/CAMER/IFS-WR/31Jan1940 - 31Dec2016/1MON/EFS-1/
/DAILYCH8/CAMER/IFT-CP/31Jan1940 - 31Dec2016/1MON/CP/
/DAILYCH8/CAMER/IFT-CP/01Jan1940 - 31Dec2016/1DAY/CP DAILY/
/DAILYCH8/CAMER/IFT-WR/01Jan1940 - 31Dec2016/1DAY/EFS-1/
/DAILYCH8/CAMER/IFT-WR/31Jan1940 - 31Dec2016/1MON/EFS-1/
/DAILYCH8/HEMP/IFS-CP/01Jan1940 - 31Dec2016/1DAY/CP DAILY/
/DAILYCH8/HEMP/IFS-CP/01Jan1940 - 31Dec2016/1DAY/EFS-2/
/DAILYCH8/HEMP/IFS-WR/01Jan1940 - 31Dec2016/1MON/EFS-2/
/DAILYCH8/HEMP/IFT-CP/31Jan1940 - 31Dec2016/1MON/CP/
/DAILYCH8/HEMP/IFT-CP/01Jan1940 - 31Dec2016/1DAY/CP DAILY/
/DAILYCH8/HEMP/IFT-WR/01Jan1940 - 31Dec2016/1DAY/EFS-2/
/DAILYCH8/HEMP/IFT-WR/31Jan1940 - 31Dec2016/1MON/EFS-2/

```

Figure 8.5 *HEC-DSSVue* Main Window with Pathname Part C Search Menu Activated

The pathname is automatically assigned by *SIMD* as follows.

- Part A: Filename root of *SIMD* input DAT file and output DSS, SUB, and OUT files.
- Part B: Control point identifier Camer or Hempt.
- Part C: Type of variable defined as either instream flow target (IFT) or instream flow shortage (IFS) for either a water right (WR) or control point (CP).
- Part D: Hydrologic period-of-analysis of January 1, 1940 through December 31, 2017.
- Part E: Time interval for data of either a day or month.
- Part F: Water right identifier (EFS-1 or EFS-2) for water right output data or the terms CP or CP-DAILY for monthly and daily control point output data.

The list of records can be limited to any subset. The data records can be searched and grouped by any combination of pathname parts. The pull-down menu for part C is shown in Figure 8.5. Any number of records can be selected for operations, with the selected records being listed in the selection box in the lower portion of the window. For example, the sub-set of all records with monthly data can be listed and selected using pathname part E and then tabulated using the display feature to obtain the tabulation of monthly data shown as Figure 8.6.

Ordinate	Date / Time	CAMER IFT-CP CP		CAMER IFT-WR EFS-1		CAMER IFS-CP CP		CAMER IFS-WR EFS-1		HEMP IFT-CP CP		HEMP IFT-WR EFS-2		HEMP IFS-CP CP		HEMP IFS-WR EFS-2	
		AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM	AC-F1 PER-CUM
1	31 Jan 40, 24:00	2,402	2,402	0	0	22	22	34,383	34,383	9,262	9,262	12,643	12,643	0	0	0	0
2	29 Feb 40, 24:00	11,713	11,713	0	0	1,343	1,343	49,666	49,666	0	0	2,386	2,386	0	0	0	0
3	31 Mar 40, 24:00	2,594	2,594	0	0	56	56	34,462	34,462	10,690	10,690	12,213	12,213	0	0	0	0
4	30 Apr 40, 24:00	54,164	54,164	0	0	28,594	28,594	44,057	44,057	0	0	16,312	16,312	0	0	0	0
5	31 May 40, 24:00	6,704	6,704	0	0	940	940	65,792	65,792	0	0	0	0	0	0	0	0
6	30 Jun 40, 24:00	7,447	7,447	0	0	2,027	2,027	66,010	66,010	0	0	0	0	0	0	0	0
7	31 Jul 40, 24:00	94,686	94,686	0	0	326	326	89,455	89,455	0	0	5,189	5,189	0	0	0	0
8	31 Aug 40, 24:00	9,838	9,838	1,752	4,279	81,778	81,778	0	0	0	0	43,028	43,028	0	0	0	0
9	30 Sep 40, 24:00	9,521	9,521	5,615	5,891	79,140	79,140	2,797	2,797	0	0	21,697	21,697	0	0	0	0
10	31 Oct 40, 24:00	9,838	9,838	8,808	8,808	81,778	81,778	48,511	48,511	0	0	53,696	53,696	0	0	0	0
11	30 Nov 40, 24:00	73,509	73,509	0	0	39,577	39,577	221,415	221,415	0	0	75,689	75,689	0	0	0	0
12	31 Dec 40, 24:00	28,284	28,284	0	0	2,682	2,682	177,699	177,699	0	0	5,195	5,195	0	0	0	0
13	31 Jan 41, 24:00	28,284	28,284	0	0	0	0	177,699	177,699	0	0	4,309	4,309	0	0	0	0
14	28 Feb 41, 24:00	25,547	25,547	0	0	867	867	160,503	160,503	0	0	4,349	4,349	0	0	0	0
15	31 Mar 41, 24:00	114,193	114,193	0	0	0	0	264,516	264,516	0	0	0	0	0	0	0	0
16	30 Apr 41, 24:00	45,223	45,223	0	0	0	0	204,694	204,694	0	0	0	0	0	0	0	0
17	31 May 41, 24:00	46,731	46,731	0	0	0	0	211,517	211,517	0	0	0	0	0	0	0	0
18	30 Jun 41, 24:00	45,223	45,223	0	0	0	0	204,694	204,694	0	0	0	0	0	0	0	0
19	31 Jul 41, 24:00	104,470	104,470	0	0	2,650	2,650	154,847	154,847	0	0	0	0	0	0	0	0
20	31 Aug 41, 24:00	20,291	20,291	0	0	3,869	3,869	126,050	126,050	0	0	12,888	12,888	0	0	0	0
21	30 Sep 41, 24:00	19,636	19,636	0	0	5,304	5,304	121,984	121,984	0	0	22,964	22,964	0	0	0	0
22	31 Oct 41, 24:00	20,291	20,291	0	0	1,377	1,377	126,050	126,050	0	0	5,792	5,792	0	0	0	0
23	30 Nov 41, 24:00	27,372	27,372	3,182	5,843	299,424	299,424	0	0	0	0	21,433	21,433	0	0	0	0
24	31 Dec 41, 24:00	28,284	28,284	2,712	177,699	49,310	49,310	50,855	50,855	0	0	80,561	80,561	0	0	0	0
25	31 Jan 42, 24:00	28,284	28,284	11,946	177,699	81,872	81,872	87,985	87,985	0	0	154,734	154,734	0	0	0	0
26	28 Feb 42, 24:00	25,547	25,547	10,817	10,817	160,503	160,503	154,734	154,734	0	0	37,141	37,141	0	0	0	0
27	31 Mar 42, 24:00	46,731	46,731	36,021	36,021	211,517	211,517	258,637	258,637	0	0	0	0	0	0	0	0
28	30 Apr 42, 24:00	112,000	112,000	0	0	5,864	5,864	211,517	211,517	0	0	0	0	0	0	0	0
29	31 May 42, 24:00	46,731	46,731	0	0	0	0	204,694	204,694	0	0	0	0	0	0	0	0
30	30 Jun 42, 24:00	45,223	45,223	0	0	0	0	150,169	150,169	0	0	20,879	20,879	0	0	0	0
31	31 Jul 42, 24:00	39,754	39,754	4,758	5,173	145,723	145,723	77,347	77,347	0	0	80,184	80,184	0	0	0	0
32	31 Aug 42, 24:00	20,291	20,291	0	0	9,930	9,930	122,798	122,798	0	0	1,048	1,048	0	0	0	0
33	30 Sep 42, 24:00	19,636	19,636	0	0	0	0	126,050	126,050	0	0	14,411	14,411	0	0	0	0
34	31 Oct 42, 24:00	20,291	20,291	0	0	639	639	257,340	257,340	0	0	2,525	2,525	0	0	0	0
35	30 Nov 42, 24:00	51,694	51,694	0	0	0	0	210,664	210,664	0	0	26,685	26,685	0	0	0	0
36	31 Dec 42, 24:00	28,284	28,284	0	0	0	0	219,011	219,011	0	0	13,770	13,770	0	0	0	0
37	31 Jan 43, 24:00	28,284	28,284	0	0	1,408	1,408	160,503	160,503	76,919	76,919	76,919	76,919	0	0	0	0
38	28 Feb 43, 24:00	25,547	25,547	0	0	165	165	116,826	116,826	0	0	34,021	34,021	0	0	0	0
39	31 Mar 43, 24:00	41,281	41,281	0	0	1,300	1,300	113,058	113,058	0	0	5,334	5,334	0	0	0	0
40	30 Apr 43, 24:00	40,930	40,930	0	0	1,593	1,593	116,826	116,826	0	0	16,165	16,165	0	0	0	0
41	31 May 43, 24:00	19,061	19,061	0	0	8,797	8,797	113,058	113,058	0	0	20,781	20,781	0	0	0	0
42	30 Jun 43, 24:00	18,446	18,446	6,009	5,183	86,896	86,896	26,371	26,371	0	0	33,131	33,131	0	0	0	0
43	31 Jul 43, 24:00	13,491	13,491	5,820	5,882	87,977	87,977	46,291	46,291	0	0	50,647	50,647	0	0	0	0
44	31 Aug 43, 24:00	9,838	9,838	5,843	6,451	86,817	86,817	45,340	45,340	0	0	48,829	48,829	0	0	0	0
45	30 Sep 43, 24:00	16,414	16,414	5,726	6,828	81,778	81,778	16,867	16,867	0	0	35,731	35,731	0	0	0	0
46	31 Oct 43, 24:00	12,350	12,350	0	0	168	168	32,375	32,375	4,926	4,926	5,525	5,525	0	0	0	0
47	30 Nov 43, 24:00	3,267	3,267	98	968	43,327	43,327	4,401	4,401	0	0	3,808	3,808	0	0	0	0
48	31 Dec 43, 24:00	6,764	6,764	0	0	5,107	5,107	85,131	85,131	0	0	0	0	0	0	0	0
49	31 Jan 44, 24:00	17,806	17,806	0	0	0	0	52,919	52,919	0	0	0	0	0	0	0	0
50	29 Feb 44, 24:00	6,327	6,327	0	0	20	20	116,826	116,826	0	0	0	0	0	0	0	0
51	31 Mar 44, 24:00	85,862	85,862	0	0	0	0	113,058	113,058	0	0	0	0	0	0	0	0
52	30 Apr 44, 24:00	18,446	18,446	0	0	177,221	177,221	0	0	0	0	0	0	0	0	0	0
53	31 May 44, 24:00	19,061	19,061	0	0	3,022	3,022	81,778	81,778	4,397	4,397	34,620	34,620	0	0	0	0
54	30 Jun 44, 24:00	18,446	18,446	0	0	3,597	3,597	147,895	147,895	0	0	32,682	32,682	0	0	0	0
55	31 Jul 44, 24:00	36,313	36,313	0	0	0	0	88,542	88,542	0	0	0	0	0	0	0	0
56	31 Aug 44, 24:00	9,838	9,838	0	0	0	0	88,542	88,542	0	0	0	0	0	0	0	0
57	30 Sep 44, 24:00	9,521	9,521	0	0	0	0	79,974	79,974	0	0	0	0	0	0	0	0
58	31 Oct 44, 24:00	9,838	9,838	0	0	0	0	264,516	264,516	0	0	0	0	0	0	0	0
59	30 Nov 44, 24:00	29,698	29,698	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	31 Dec 44, 24:00	11,683	11,683	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	31 Jan 45, 24:00	11,683	11,683	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	28 Feb 45, 24:00	10,552	10,552	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	31 Mar 45, 24:00	114,148	114,148	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 8.6 HEC-DSSVue Tabular Display Window with the Eight Monthly Records Selected

The *Display* and *Edit* windows of HEC-DSSVue can be employed with the selected data being displayed in either tabular or graphical format. The plot features accessed through the *Display* pull-down menu provides flexible capabilities for creating and editing time series plots. The *Tabulate* options accessed through the *Display* menu allows quantities to be changed, the number of decimal places to be set, summation of selected subsets of data, and automated detection of missing data. The *Edit* pull-down menu accesses various data management options. Edit features for renaming any or all pathname parts of groups of selected records and copying records between DSS files are employed later in this chapter to convert IFT records in the *SIMD* simulation results output DSS file to *TS* records in a *SIM* input DSS file. Statistical analysis and mathematical capabilities are accessed through the *Tools* menu. Chapter 6 of the *WRAP Users Manual* summarizes *HEC-DSSVue* capabilities and WRAP applications of DSS. The *HEC-DSSVue User's Manual* provides detailed documentation of the extensive data management, manipulation, and analysis capabilities provided by *HEC-DSSVue*.

Monthly WAM with Instream Flow Targets from the Daily WAM

A strategy for incorporating monthly instream flow targets computed in a daily *SIMD* simulation into the *SIM* input dataset for a monthly WAM is outlined on the last page (page 132) of Chapter 6. Daily targets computed by *SIMD* are aggregated within *SIMD* to monthly targets which are included in the *SIMD* simulation results. These time series of monthly targets in acre-feet/month are converted to *TS* records incorporated in a *SIM* input dataset.

Although a set of monthly time series *TS* records can be created from *SIMD* simulation results without using DSS files, the use of DSS for this task is very convenient. DSS is the recommended strategy for managing *SIM/SIMD* time series input data and simulation results. DSS records are quickly and easily renamed in the *HEC-DSSVue* editor and copied to another DSS file. The *TS* records of monthly instream flow targets are copied from the *SIMD* output DSS file to the hydrology input DSS file that also contains the *IN*, *EV*, *DF*, and *HI* records.

Monthly SIM Water Availability Model (WAM)

The DAT file for the WAM discussed in this final section of Chapter 8 consists of the DAT file for the *Fundamentals Manual* example presented in Appendix A of the *Fundamentals Manual* with the two *IF* record water rights presented in Table 8.26 added to replace the two original *IF* record water rights. A one is entered for DSSTS in *JO* record field 7 to signal that *TS* records are read from the DSS file. Time series *TS* records containing instream flow targets in units of acre-feet/month for the two *IF* record instream flow rights are added to the hydrology input DSS file. Water rights EFS-1 and EFS-2 at control points Camer and Hemp model the SB3 environmental flow standards defined in Tables 8.1, 8.2, and 8.4.

Table 8.26
Records for *IF* Record Rights in DAT File

IF Camer		999999	EFS-1
TS	DSS		
IF Hemp		999999	EFS-2
TS	DSS		

The instream flow targets for water rights EFS-1 and EFS-2 in units of acre-feet are read from DSS records in the hydrology input DSS file, which has the filename ExamplesHYD.DSS. The pathnames for the *TS* records are as follows.

<u>Part A</u>	<u>Part B</u>	<u>Part C</u>	<u>Part D</u>	<u>Part E</u>
EXAMPLES	CAMER	TS	01Jan1940-31Dec2017	1MON
EXAMPLES	HEMP	TS	01Jan1940-31Dec2017	1MON

All *IN*, *EV*, *TS*, *HI*, and *TS* input records read by one or more of the examples in Chapters 7 and 8 are stored in a single hydrology input DSS file with the filename ExamplesHYD.DSS. The filename root "Examples" excluding the appended "HYD" is entered in field 13 of the *OF* record. This *OF* record field 13 file naming option is designed for added convenience when employing the same DSS input file with multiple DAT files with different filename roots.

Instream Flow Targets and Shortages

The monthly instream flow targets for EFS-1 and EFS-2 at control points Camer and Hemp in cfs are tabulated in Tables 8.27 and 8.28. The quantities in Tables 8.27 and 8.28 were computed as daily volumes in acre-feet/day and summed to monthly volumes in acre-feet/month within *SIMD* and converted to cubic feet per second (cfs) within *TABLES* using the CFS feature (field 10) of the 2IFT time series record. The daily and monthly instream flow targets are also plotted in Figures 8.7, 8.8, 8.9, and 8.10 in units of cfs. A daily flow rate of 1.00 acre-foot/day is equivalent to 0.50416667 cfs. The conversion to a mean monthly flow rate in cfs from a monthly volume in acre-feet depends upon the number of days in the months.

Table 8.27
Monthly Means in cfs of Final Daily Instream Flow Targets for EFS-1 at Camer
Including Subsistence, Base, and High Flow Pulse Components

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	60.	171.	80.	471.	84.	110.	1535.	160.	160.	160.	752.	460.	352.
1941	460.	460.	1837.	760.	760.	760.	1451.	330.	330.	330.	460.	460.	703.
1942	460.	460.	310.	1401.	310.	310.	330.	635.	330.	330.	869.	460.	515.
1943	460.	460.	669.	670.	310.	310.	543.	160.	160.	160.	82.	78.	338.
1944	204.	110.	1356.	310.	310.	310.	482.	160.	160.	160.	474.	190.	355.
1945	190.	190.	1886.	760.	760.	760.	601.	330.	330.	330.	251.	395.	569.
1946	190.	190.	1886.	760.	760.	760.	634.	195.	160.	160.	915.	460.	592.
1947	460.	460.	1386.	310.	310.	310.	542.	160.	160.	160.	314.	190.	398.
1948	190.	293.	310.	448.	659.	310.	304.	209.	160.	160.	158.	32.	269.
1949	55.	43.	550.	1051.	310.	310.	160.	160.	160.	160.	190.	190.	279.
1950	190.	524.	310.	896.	618.	310.	325.	160.	612.	160.	190.	190.	371.
1951	190.	190.	49.	36.	84.	405.	32.	32.	77.	32.	32.	32.	98.
1952	32.	32.	40.	380.	158.	108.	85.	32.	32.	32.	42.	177.	96.
1953	71.	47.	50.	294.	102.	104.	224.	55.	50.	65.	370.	293.	144.
1954	190.	190.	32.	57.	79.	32.	32.	32.	33.	45.	173.	32.	76.
1955	44.	56.	56.	440.	112.	127.	232.	50.	62.	50.	33.	37.	108.
1956	49.	151.	32.	47.	486.	59.	32.	40.	32.	32.	150.	65.	98.
1957	41.	50.	484.	106.	96.	140.	330.	543.	407.	330.	818.	460.	319.
1958	460.	460.	1911.	760.	760.	760.	530.	507.	330.	330.	190.	190.	601.
1959	190.	377.	310.	640.	455.	681.	458.	264.	191.	160.	501.	190.	367.
1960	190.	190.	310.	431.	438.	310.	242.	160.	301.	160.	482.	190.	283.
1961	190.	190.	1311.	760.	760.	1355.	1312.	160.	160.	160.	468.	190.	587.
1962	190.	190.	310.	625.	520.	808.	336.	196.	609.	160.	508.	190.	386.
1963	190.	190.	84.	107.	140.	85.	168.	33.	41.	47.	64.	114.	105.
1964	63.	99.	475.	111.	100.	71.	74.	63.	64.	78.	482.	190.	156.
1965	190.	190.	504.	1018.	345.	310.	455.	160.	160.	160.	495.	190.	348.

1966	190.	190.	600.	1082.	310.	310.	671.	160.	160.	160.	190.	190.	352.
1967	190.	190.	91.	91.	487.	68.	195.	44.	65.	63.	508.	190.	182.
1968	190.	190.	1911.	760.	760.	760.	2011.	330.	330.	330.	603.	728.	748.
1969	460.	460.	1174.	1329.	760.	760.	473.	160.	160.	160.	190.	498.	549.
1970	190.	190.	1396.	310.	310.	310.	607.	160.	160.	160.	190.	190.	350.
1971	190.	190.	84.	107.	80.	40.	232.	59.	88.	83.	324.	293.	147.
1972	190.	190.	310.	310.	602.	633.	498.	160.	160.	160.	377.	286.	324.
1973	190.	190.	966.	691.	310.	310.	952.	330.	330.	330.	842.	460.	494.
1974	460.	460.	310.	310.	1002.	310.	404.	160.	160.	160.	930.	460.	427.
1975	460.	460.	760.	1600.	760.	760.	1131.	330.	330.	330.	190.	190.	608.
1976	190.	190.	91.	505.	119.	113.	1505.	160.	160.	160.	637.	628.	373.
1977	460.	460.	1288.	1228.	760.	760.	663.	160.	160.	160.	75.	62.	520.
1978	63.	150.	80.	71.	72.	81.	224.	44.	43.	38.	90.	104.	88.
1979	172.	110.	1416.	310.	310.	310.	1390.	330.	330.	330.	190.	190.	454.
1980	274.	293.	669.	310.	1027.	310.	613.	160.	160.	160.	70.	102.	348.
1981	89.	110.	478.	122.	88.	97.	726.	364.	160.	160.	642.	460.	293.
1982	460.	460.	310.	681.	1057.	310.	330.	330.	330.	330.	190.	190.	415.
1983	190.	517.	1123.	323.	310.	310.	766.	160.	160.	160.	190.	190.	367.
1984	190.	190.	310.	310.	310.	310.	37.	32.	32.	260.	271.	383.	220.
1985	190.	190.	1218.	760.	760.	1329.	214.	160.	243.	160.	501.	190.	493.
1986	190.	190.	310.	310.	861.	684.	480.	241.	609.	160.	869.	460.	447.
1987	460.	460.	1311.	760.	1335.	760.	990.	330.	330.	330.	359.	262.	643.
1988	190.	190.	310.	310.	310.	1395.	557.	160.	160.	160.	166.	33.	328.
1989	54.	77.	669.	310.	1047.	310.	160.	160.	160.	160.	190.	190.	293.
1990	190.	190.	669.	1082.	310.	310.	160.	217.	335.	160.	260.	190.	339.
1991	389.	190.	310.	1051.	669.	310.	188.	319.	184.	160.	804.	460.	420.
1992	460.	460.	1911.	760.	760.	760.	1179.	330.	330.	330.	633.	673.	719.
1993	460.	460.	1862.	760.	760.	760.	634.	330.	330.	330.	190.	222.	593.
1994	190.	410.	310.	310.	1274.	310.	327.	355.	160.	160.	460.	900.	432.
1995	460.	460.	1886.	760.	760.	760.	911.	330.	330.	330.	190.	190.	616.
1996	190.	190.	79.	58.	86.	121.	257.	53.	82.	97.	321.	333.	155.
1997	190.	190.	1911.	760.	760.	760.	1928.	330.	330.	330.	460.	900.	744.
1998	460.	460.	1862.	760.	760.	760.	287.	71.	70.	81.	501.	190.	522.
1999	190.	190.	679.	310.	669.	310.	1109.	160.	160.	160.	141.	32.	345.
2000	44.	41.	75.	451.	68.	64.	87.	32.	43.	50.	508.	190.	137.
2001	190.	190.	1720.	760.	760.	760.	861.	160.	160.	160.	508.	190.	538.
2002	190.	190.	310.	310.	310.	310.	1338.	160.	160.	160.	501.	190.	346.
2003	190.	190.	1017.	310.	310.	310.	1145.	160.	160.	160.	190.	190.	364.
2004	383.	273.	310.	1401.	310.	310.	1055.	330.	330.	330.	899.	460.	533.
2005	460.	460.	1862.	760.	760.	760.	899.	160.	160.	160.	204.	75.	562.
2006	44.	68.	56.	464.	125.	135.	265.	63.	50.	68.	40.	163.	129.
2007	99.	102.	1446.	310.	310.	310.	2080.	330.	330.	330.	460.	460.	553.
2008	460.	460.	310.	310.	1386.	310.	274.	66.	45.	64.	257.	190.	345.
2009	190.	190.	78.	466.	76.	93.	208.	39.	66.	95.	489.	190.	181.
2010	190.	190.	1862.	760.	760.	760.	284.	269.	160.	160.	190.	190.	484.
2011	325.	190.	116.	100.	123.	88.	229.	61.	38.	80.	32.	59.	120.
2012	157.	57.	1436.	310.	310.	310.	408.	40.	44.	34.	32.	32.	267.
2013	154.	38.	41.	48.	96.	35.	242.	32.	77.	60.	489.	190.	125.
2014	190.	190.	54.	46.	285.	58.	391.	160.	392.	160.	358.	190.	206.
2015	269.	190.	1247.	310.	310.	310.	1221.	330.	330.	330.	930.	460.	523.
2016	460.	460.	760.	2000.	760.	760.	719.	330.	330.	330.	617.	643.	680.
2017	460.	460.	310.	603.	310.	310.	364.	394.	160.	160.	190.	482.	350.
MEAN	240.	249.	746.	550.	484.	415.	594.	196.	200.	177.	373.	272.	376.

Table 8.28
Monthly Means in cfs of Final Daily Instream Flow Targets for EFS-2 at Hemp
Including Subsistence, Base, and High Flow Pulse Components

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	516.	833.	511.	648.	834.	944.	1455.	1330.	1330.	1330.	3721.	2890.	1363.
1941	2890.	2890.	4302.	3440.	3440.	3440.	2584.	2050.	2050.	2050.	4495.	2890.	3041.
1942	2890.	2890.	1900.	1900.	1900.	1900.	2050.	2050.	2354.	2050.	2890.	2890.	2301.
1943	2890.	2890.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1413.	510.	542.	1645.
1944	1333.	920.	1900.	1900.	2882.	1900.	1330.	1330.	1502.	1330.	2011.	1440.	1652.
1945	1440.	1440.	4302.	3440.	3440.	3440.	2442.	2050.	2050.	2050.	1440.	2304.	2494.
1946	1440.	1440.	4302.	3440.	3440.	3440.	1330.	1330.	1545.	1330.	4405.	2890.	2529.
1947	2890.	2890.	1900.	1900.	1900.	1900.	1330.	1455.	1330.	1330.	1440.	1667.	1821.

1948	1440.	1790.	1900.	1900.	1900.	1900.	1498.	1330.	1330.	1330.	510.	510.	1442.
1949	642.	1070.	1900.	1900.	1900.	1900.	1407.	1330.	1416.	1412.	1940.	1440.	1522.
1950	1969.	1956.	1900.	1900.	1900.	1900.	1455.	1388.	1330.	1330.	1440.	1440.	1657.
1951	1440.	1440.	570.	572.	631.	717.	510.	510.	539.	510.	510.	510.	700.
1952	510.	510.	536.	787.	744.	636.	517.	510.	510.	510.	1005.	814.	632.
1953	686.	654.	838.	593.	1104.	561.	724.	510.	539.	642.	1822.	2012.	892.
1954	1440.	1440.	510.	634.	795.	510.	510.	510.	510.	510.	585.	510.	701.
1955	510.	1157.	580.	786.	718.	625.	510.	514.	639.	731.	510.	510.	645.
1956	510.	510.	510.	510.	650.	510.	510.	510.	510.	510.	537.	592.	531.
1957	510.	1156.	530.	1256.	1130.	1130.	2513.	2050.	2050.	2050.	4808.	2890.	1840.
1958	2890.	2890.	4302.	3440.	3440.	3440.	2442.	2050.	2050.	2050.	1440.	1440.	2655.
1959	1440.	2097.	1900.	1900.	1900.	1900.	1485.	1330.	1330.	1372.	2390.	1716.	1725.
1960	1440.	1440.	1900.	1900.	1900.	1900.	1499.	1330.	1330.	1330.	2197.	1440.	1633.
1961	1440.	1440.	4302.	3440.	3440.	3440.	1532.	1330.	1330.	1330.	2081.	1990.	2261.
1962	1440.	1440.	1900.	1900.	1900.	1900.	1413.	1372.	1330.	1330.	1725.	2364.	1669.
1963	1440.	1440.	536.	744.	662.	789.	510.	510.	510.	531.	557.	510.	723.
1964	553.	696.	856.	701.	600.	613.	510.	510.	767.	564.	2426.	1440.	851.
1965	1440.	1440.	1900.	1900.	2882.	1900.	1330.	1330.	1448.	1438.	2325.	1440.	1732.
1966	1440.	1440.	1900.	2915.	1900.	1900.	1330.	1496.	1330.	1330.	1440.	1440.	1654.
1967	1440.	1440.	510.	753.	674.	784.	616.	510.	518.	538.	2692.	1440.	987.
1968	1440.	1440.	4302.	3440.	3440.	3440.	2246.	2050.	2050.	2050.	3167.	4730.	2825.
1969	2890.	2890.	4302.	3440.	3440.	3440.	1330.	1330.	1373.	1330.	1440.	2547.	2477.
1970	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1588.	1330.	1664.	1440.	1596.
1971	1440.	1440.	521.	593.	625.	558.	689.	681.	510.	567.	1907.	2253.	979.
1972	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1455.	1330.	1413.	2661.	1440.	1675.
1973	1440.	1440.	1900.	1900.	1900.	1900.	2305.	2050.	2050.	2381.	3657.	3412.	2199.
1974	3694.	2890.	1900.	1900.	1900.	1900.	1330.	1439.	1373.	1330.	3721.	2890.	2183.
1975	2890.	2890.	3440.	4331.	3440.	3440.	2442.	2050.	2050.	2050.	1440.	1440.	2655.
1976	1440.	1440.	704.	1018.	1130.	981.	1538.	1330.	1330.	1330.	2890.	4990.	1680.
1977	2890.	2890.	4302.	3440.	3440.	3440.	1330.	1330.	1330.	1330.	510.	559.	2228.
1978	673.	1406.	777.	620.	510.	613.	510.	859.	510.	510.	510.	510.	662.
1979	1162.	920.	1900.	1900.	1900.	1900.	2472.	2050.	2050.	2050.	1440.	1440.	1772.
1980	2434.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1496.	510.	510.	1500.
1981	510.	510.	720.	702.	830.	1370.	1584.	1330.	1330.	1330.	2890.	2890.	1337.
1982	2890.	2890.	1900.	1900.	1900.	1900.	2246.	2050.	2050.	2050.	1440.	1925.	2092.
1983	1440.	2204.	1900.	1900.	1900.	1900.	1330.	1529.	1397.	1330.	1440.	1440.	1638.
1984	1440.	1440.	1900.	1900.	1900.	1900.	510.	510.	510.	984.	1928.	1440.	1361.
1985	1440.	1440.	4302.	3440.	3440.	3440.	1330.	1330.	1330.	1455.	2125.	1440.	2212.
1986	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1502.	1330.	3998.	3756.	1978.
1987	2890.	2890.	4302.	3440.	3440.	3440.	2316.	2050.	2050.	2050.	1440.	1976.	2690.
1988	1783.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	510.	1430.
1989	952.	911.	1900.	1900.	1900.	1900.	1330.	1496.	1330.	1330.	1440.	1440.	1489.
1990	1440.	1707.	1900.	2577.	1900.	1900.	1330.	1330.	1459.	1332.	1440.	1440.	1644.
1991	1992.	1440.	1900.	1900.	1900.	1900.	1330.	1538.	1330.	1330.	3444.	3180.	1934.
1992	2890.	2890.	4302.	3440.	3440.	3440.	2526.	2050.	2050.	2050.	2890.	4927.	3077.
1993	2890.	2890.	4302.	3440.	3440.	3440.	2344.	2050.	2050.	2050.	1440.	1440.	2647.
1994	1440.	2096.	2023.	1900.	1900.	1900.	1330.	1330.	1330.	1538.	2890.	4230.	1991.
1995	2890.	2890.	4302.	3440.	3440.	3440.	2050.	2344.	2050.	2050.	1440.	1970.	2692.
1996	1440.	1440.	510.	512.	510.	510.	510.	743.	745.	515.	1868.	2298.	963.
1997	1440.	1440.	4302.	3440.	3440.	3440.	2246.	2050.	2050.	2050.	2890.	4166.	2755.
1998	2890.	2890.	4302.	3440.	3440.	3440.	510.	510.	738.	796.	2651.	1440.	2245.
1999	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1330.	1330.	510.	510.	1401.
2000	525.	510.	749.	672.	677.	882.	510.	510.	510.	649.	2011.	1440.	804.
2001	1440.	1440.	4302.	3440.	3440.	3440.	1386.	1330.	1416.	1330.	2140.	1440.	2214.
2002	1440.	1440.	1900.	1900.	1900.	1900.	1558.	1330.	1330.	1330.	1885.	1440.	1613.
2003	1440.	1440.	1900.	1900.	1900.	1900.	1330.	1330.	1410.	1460.	1440.	1440.	1574.
2004	2674.	1482.	1900.	1900.	1900.	1900.	2246.	2050.	2050.	2050.	4030.	2890.	2260.
2005	2890.	2890.	4302.	3440.	3440.	3440.	1330.	1455.	1330.	1330.	510.	510.	2234.
2006	526.	602.	878.	766.	839.	510.	510.	510.	510.	848.	551.	899.	664.
2007	1075.	567.	2555.	1900.	1900.	1900.	2246.	2050.	2050.	2050.	2890.	2890.	2016.
2008	2890.	2890.	1900.	1900.	1900.	1900.	510.	635.	511.	510.	1594.	1440.	1538.
2009	1440.	1440.	673.	783.	778.	510.	510.	510.	683.	893.	2425.	1440.	1003.
2010	1440.	1440.	4302.	3440.	3440.	3440.	1330.	1330.	1459.	1330.	1440.	1440.	2155.
2011	1747.	1440.	510.	510.	510.	510.	510.	510.	510.	538.	510.	583.	695.
2012	1098.	860.	1900.	1900.	1900.	1900.	510.	510.	510.	517.	510.	510.	1052.
2013	952.	529.	538.	510.	582.	510.	510.	510.	651.	786.	2011.	1440.	795.
2014	1440.	1440.	511.	510.	822.	854.	1330.	1330.	1330.	1330.	1980.	1440.	1191.
2015	2456.	1440.	1900.	1900.	2882.	1900.	2442.	2050.	2050.	2050.	4275.	2890.	2358.
2016	2890.	2890.	3440.	4331.	3440.	3440.	2050.	2620.	2050.	2050.	2890.	2890.	2912.
2017	4010.	4388.	1900.	1900.	1900.	1900.	1330.	1455.	1330.	1330.	1440.	2307.	2085.
MEAN	1719.	1705.	2142.	1998.	2006.	1959.	1382.	1326.	1325.	1333.	1956.	1844.	1724.

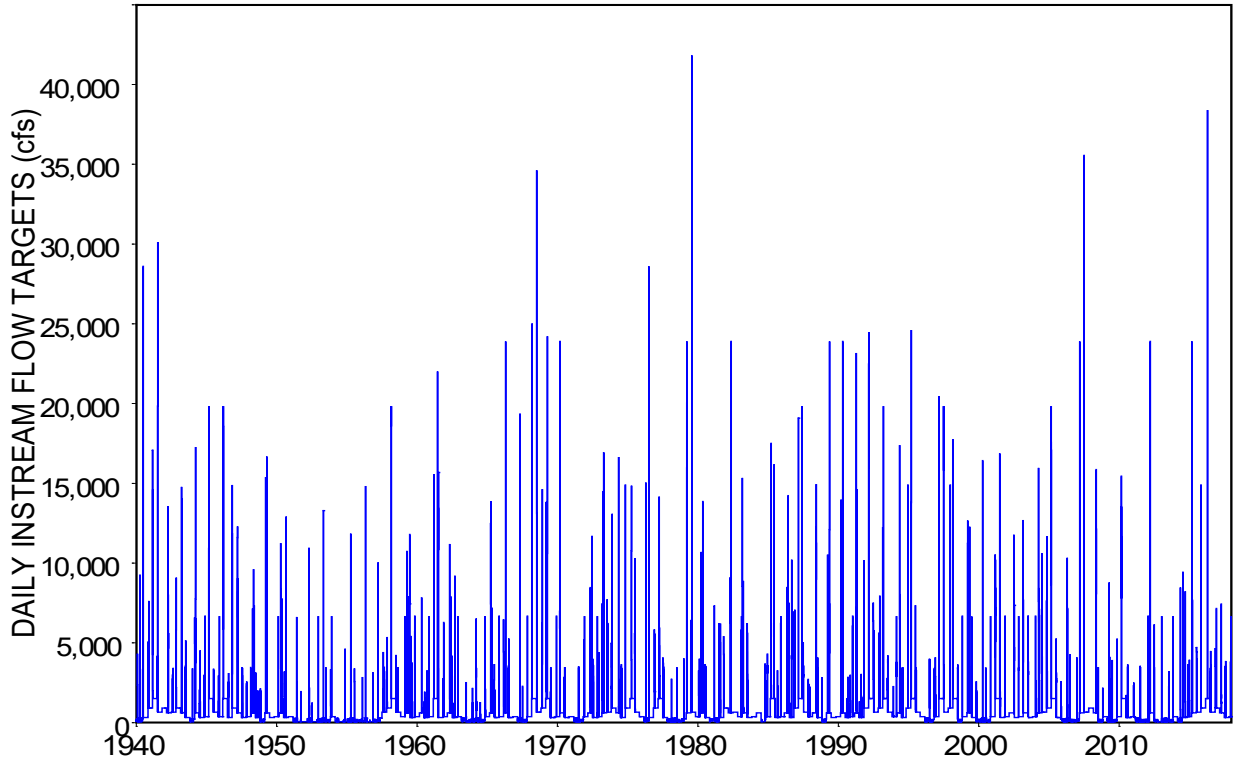


Figure 8.7 Daily Environmental Flow Targets in cfs for EFS-1 at Camer

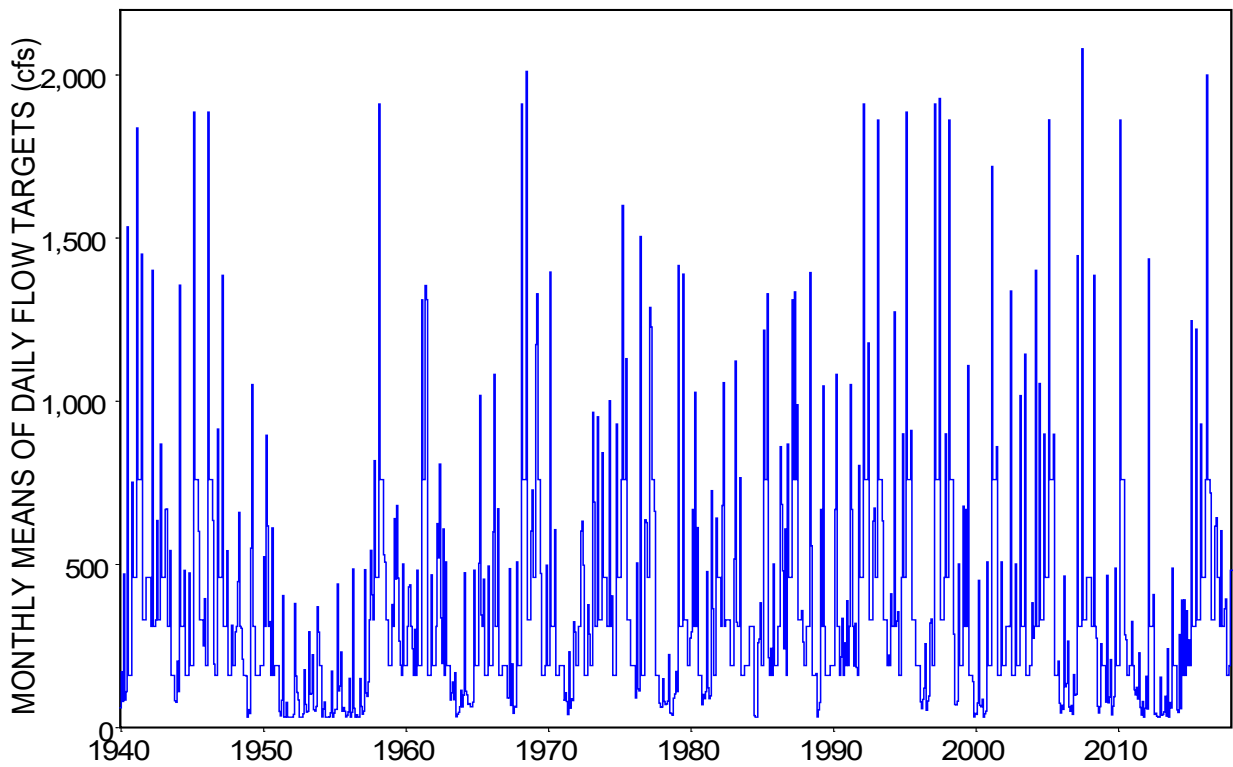


Figure 8.8 Monthly Environmental Flow Targets in cfs for EFS-1 at Camer

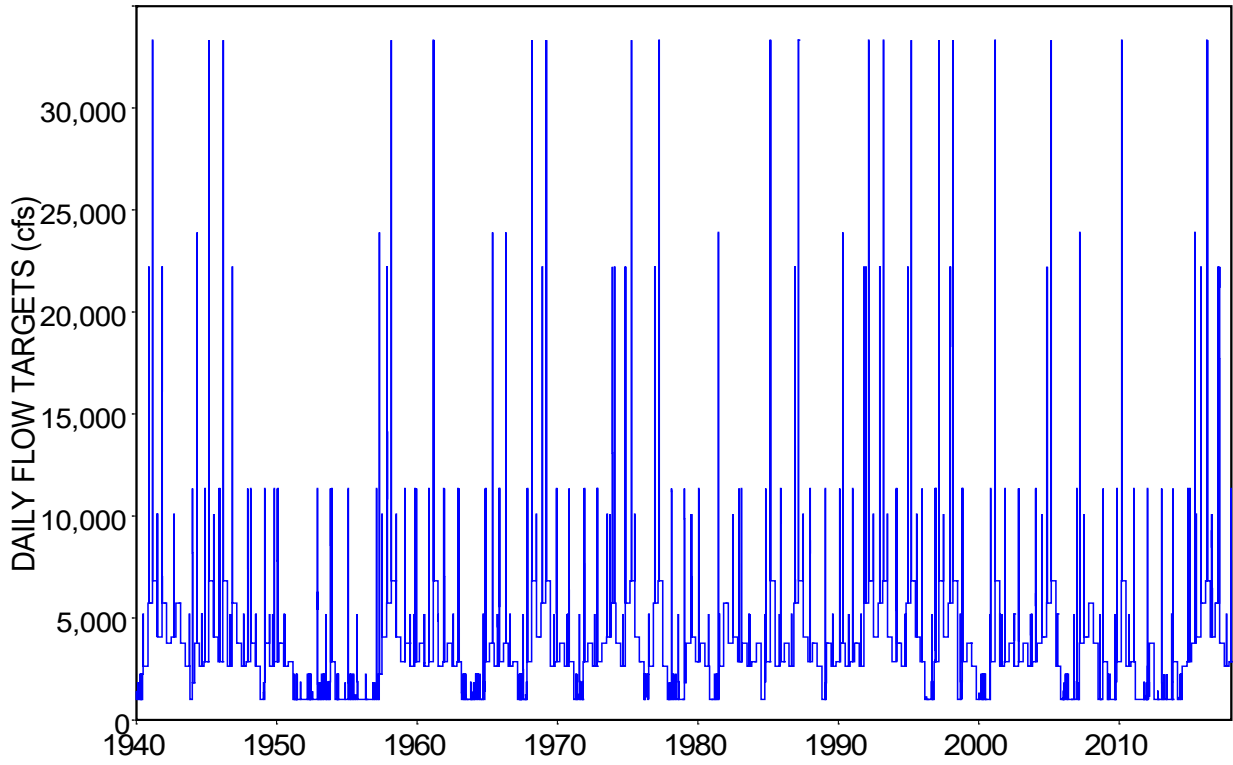


Figure 8.9 Daily Environmental Flow Targets in cfs for EFS-2 at Hemp

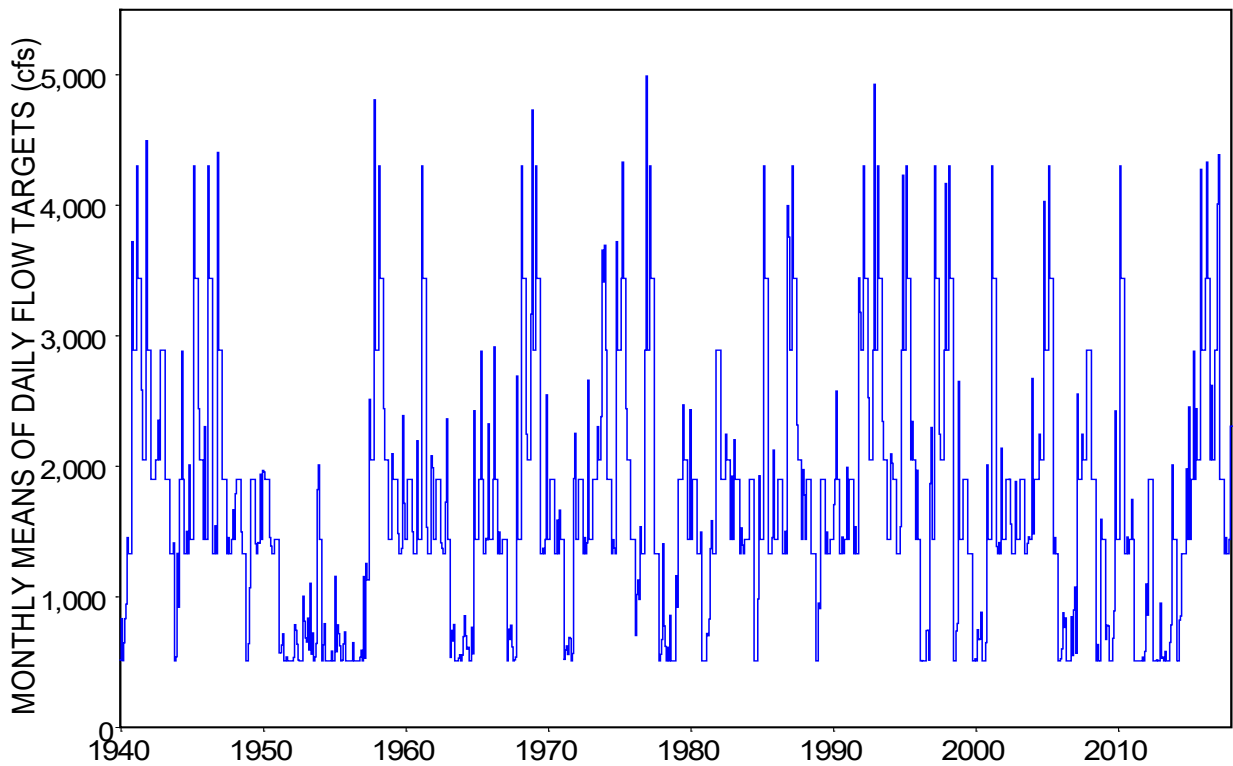


Figure 8.10 Monthly Environmental Flow Targets in cfs for EFS-2 at Hemp

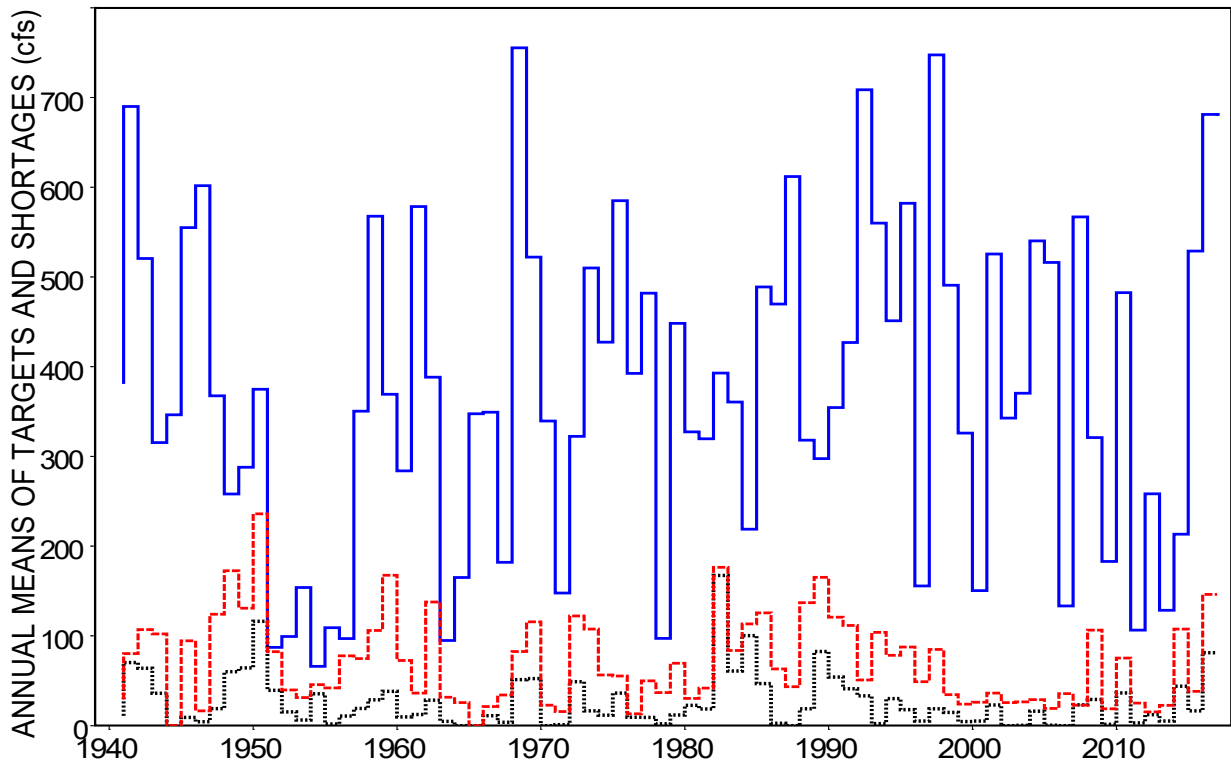


Figure 8.11 Annual Means in cfs of Targets and Shortages for EFS-1 at Camer (*SIMD/SIM* Targets (solid blue line), *SIMD* shortages (black dotted), *SIM* shortages (red dashed))

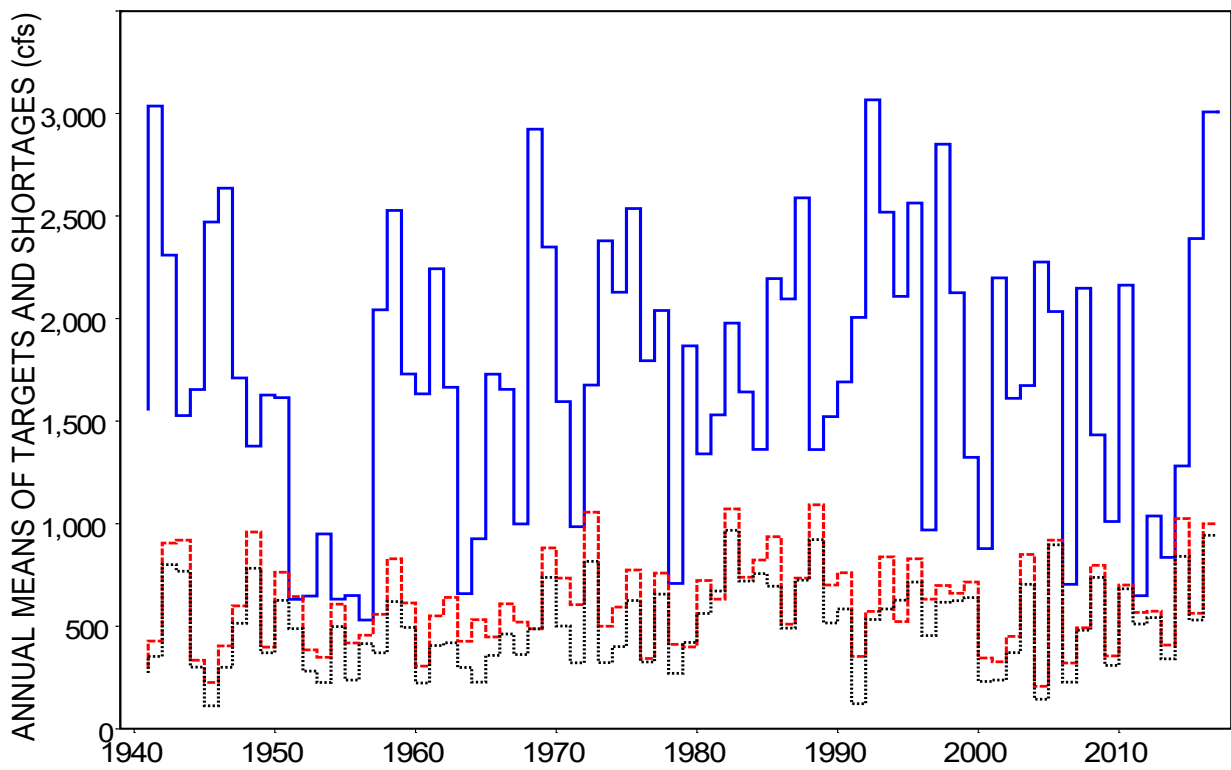


Figure 8.12 Annual Means in cfs of Targets and Shortages for EFS-2 at Hemp

The alternative variations of the DAT file in Chapters 7 and 8 contain an *IF* record water right at each of two control points. Tables 8.27 and 8.28 can be created with program *TABLES* with either of the following two sets of TIN file input records from either the: (1) *SIM* output OUT created by the monthly simulation discussed in this section or (2) monthly OUT file created by the previously discussed daily *SIMD* simulation. The times series of instream flow targets tabulated in Tables 8.26 and 8.27 can be tabulated within *HEC-DSSVue* from either the DSS input file or DSS output file for the *SIM* monthly simulation discussed here.

	2IFT	1	0	0	1	2	0	0	0	1
	IDEN			EFS-1				EFS-2		
or	2IFT	1	0	0	0	2	0	0	0	1
	IDEN	Camer		Hemp						

The following *TABLES* input records convert the monthly and daily instream flow targets and shorts from the OUT and SUB files to DSS records in a DSS file for plotting the graphs in Figures 8.7 through 8.12 with *HEC-DSSVue*.

2IFT	0	4	0	0	2	0	0	0	1
IDEN	Camer		Hemp						
2IFS	0	4	0	0	-2	0	0	0	1
6IFT	0	4	0	0	-2	0	0	0	1
6IFS	0	4	0	0	-2	0	0	0	1

The following TIN file records are employed in the frequency analyses presented in Tables 8.29 and 8.30.

2FRE	11	0	2	2	0	1		
IDEN			EFS-1				EFS-2	
2FRE	12	0	-2	2	0	1		
6FRE	11	0	-2	2	0	1		
6FRE	12	0	-2	2	0	1		
2FRE	8	0	2	2	0	1		
IDEN			Camer				Hemp	
2FRE	9	0	-2	2	0	1		

The datasets of 1940-2017 time series quantities for which each of the columns of statistical frequency metrics in Tables 8.29 and 8.30 are computed are as follows.

- Columns 2 and 3:* Daily targets and corresponding monthly summations of the daily targets from the daily *SIMD* simulation which are output to the *SIMD* simulation results DSS, OUT, and SUB output files.
- Column 4:* Monthly targets from the *TS* records in the *SIM* input dataset which can also be included in the *SIM* simulation results DSS and OUT output files. The targets reflected in columns 3 and 4 of Tables 8.29 and 8.30 are identically the same.
- Column 5:* Daily shortages corresponding to the targets reflected in column 2 which are the same for either water rights (EFS-1 and EFS-2) or control points (Camer and Hemp).
- Column 6:* Monthly shortages for water rights EFS-1 and EFS-2 computed as the summation of daily targets (column 3) less daily regulated flows.

Column 7: Monthly shortages for control points Camer and Hemp derived from monthly time series of targets reflected in the statistics in column 3 and monthly regulated flows.

Column 8: Monthly shortages corresponding the targets reflected in column 4 which are the same for either water rights EFS-1 and EFS-2 or control points Camer and Hemp.

Table 8.29
Frequency Statistics for Targets and Shortages for EFS-1 at Camer from
Monthly *SIM* Simulation and Monthly Summations from Daily *SIMD* Simulation

1	2	3	4	5	6	7	8
	Targets (cfs)			Shortages (cfs)			
	<i>SIMD</i>	<i>SIMD</i>	<i>SIM</i>	<i>SIMD</i>	<i>SIMD-WR</i>	<i>SIMD-CP</i>	<i>SIM</i>
	Daily	Monthly	Monthly	Daily	Monthly	Monthly	Monthly
Mean	375.5	374.7	374.7	72.78	72.81	26.21	69.79
Stand Dev	827.1	364.8	364.8	123.9	82.37	63.22	126.9
Minimum	32.00	32.00	32.00	0.00	0.00	0.00	0.00
99.5%	32.00	32.00	32.00	0.00	0.00	0.00	0.00
99%	32.00	32.00	32.00	0.00	0.00	0.00	0.00
98%	32.00	32.00	32.00	0.00	0.00	0.00	0.00
95%	32.00	40.66	40.66	0.00	0.00	0.00	0.00
90%	32.00	61.59	61.59	0.00	0.00	0.00	0.00
85%	56.90	81.89	81.89	0.00	2.68	0.00	0.00
80%	110.0	119.5	119.5	0.00	7.29	0.00	0.00
75%	140.0	160.0	160.0	0.00	10.85	0.00	0.00
70%	160.0	160.0	160.0	0.00	14.91	0.00	0.00
60%	190.0	190.0	190.0	0.00	26.12	0.00	0.00
50%	190.0	293.0	293.0	0.00	46.22	0.00	0.00
40%	310.0	317.1	317.1	32.00	69.99	0.00	15.33
30%	310.0	455.0	455.0	55.87	94.33	0.00	53.85
25%	330.0	460.0	460.0	126.8	107.5	11.84	99.77
20%	460.0	539.6	539.6	160.0	127.9	30.57	150.0
15%	460.0	742.7	742.7	190.0	152.8	59.30	167.9
10%	760.0	760.0	760.0	276.7	181.4	103.6	236.0
5%	760.0	1,186	1,186	330.0	249.5	166.0	330.0
2%	2,037	1,553	1,553	432.5	322.9	271.9	479.7
1%	3,649	1,886	1,886	460.0	360.0	319.5	560.8
0.5%	6,443	1,916	1,916	760.0	391.6	332.8	645.8
Maximum	21,086	2,080	2,080	760.0	562.3	444.6	1,006

Instream flow targets are computed and recorded by *SIM* and *SIMD* as daily or monthly volumes in acre-feet. Conversion of simulation results to cfs in *TABLES* facilitates direct comparison of monthly and daily quantities. *SIMD* and *TABLES* correctly account for the difference in number of days (28, 29, 30, 31) in each month. However, regardless of units, averaging 28,490 daily versus 936 monthly values is slightly different due to the varying number of days in each month. Thus, daily and monthly means of 375.5 cfs versus 374.7 cfs in columns 2 and 3 of Table 8.29 and 1,724 cfs versus 1,725 in Table 8.30 are slightly different

Table 8.30
 Frequency Statistics for Targets and Shortages for EFS-2 at Hemp from
 Monthly *SIM* Simulation and Monthly Summations from Daily *SIMD* Simulation

1	2	3	4	5	6	7	8
	Targets (cfs)			Shortages (cfs)			
	<i>SIMD</i>	<i>SIMD</i>	<i>SIM</i>	<i>SIMD</i>	<i>SIMD-WR</i>	<i>SIMD-CP</i>	<i>SIM</i>
	Daily	Monthly	Monthly	Daily	Monthly	Monthly	Monthly
Mean	1,724	1,725	1,725	749.9	749.2	502.6	610.3
Stand Dev	1,251	963.3	963.3	786.1	613.7	660.8	724.2
Minimum	510.0	510.0	510.0	0.00	0.00	0.00	0.00
99.5%	510.0	510.0	510.0	0.00	0.00	0.00	0.00
99%	510.0	510.0	510.0	0.00	0.00	0.00	0.00
98%	510.0	510.0	510.0	0.00	0.00	0.00	0.00
95%	510.0	510.0	510.0	0.00	0.00	0.00	0.00
90%	510.0	510.0	510.0	0.00	11.70	0.00	0.00
85%	510.0	587.5	587.5	0.00	101.9	0.00	0.00
80%	510.0	745.6	745.6	0.00	195.2	0.00	0.00
75%	1,130	1,130	1,130	0.00	277.9	0.00	0.00
70%	1,330	1,330	1,330	0.00	360.4	0.00	0.00
60%	1,330	1,440	1,440	467.2	488.6	0.00	0.00
50%	1,440	1,440	1,440	510.0	510.0	39.40	510.0
40%	1,900	1,900	1,900	632.7	803.0	510.0	511.4
30%	1,900	1,900	1,900	1,330	1,107	643.2	951.1
25%	2,050	2,050	2,050	1,330	1,224	971.8	1,330
20%	2,050	2,323	2,323	1,440	1,329	1,231	1,330
15%	2,890	2,890	2,890	1,440	1,351	1,330	1,412
10%	3,440	3,440	3,440	1,900	1,507	1,429	1,510
5%	3,440	3,440	3,440	2,050	1,912	1,853	1,972
2%	3,440	4,302	4,302	2,774	2,247	2,050	2,493
1%	5,720	4,320	4,320	3,125	2,494	2,430	2,890
0.5%	9,152	4,570	4,570	3,440	2,802	2,802	3,409
Maximum	16,800	4,990	4,990	3,440	3,440	3,440	3,440

The monthly time series of targets represented by the statistics in column 3 of Tables 8.29 and 8.30 consist of the summations of the daily targets of column 2.

$$IFT_{\text{month}} = \sum IFT_{\text{day}}$$

Daily shortages reflected in column 5 correspond to the daily targets of column 2. The monthly shortages for EFS-1 and EFS-2 of column 6 are summations of the daily shortages of column 5.

$$IFS_{\text{month}} = \sum IFS_{\text{day}} = \sum (IFT_{\text{day}} - RF_{\text{day}})$$

The monthly shortages for Camer and Hemp of column 7 are summations of the daily targets of column 5 less monthly regulated flows. Thus, the monthly shortages of columns 6 and 7 are defined significantly differently.

$$IFS_{\text{month}} = \sum (IFT_{\text{day}}) - (\sum RF_{\text{day}})$$

The final *SIM* monthly shortages of column 8 are the monthly targets of column 4 less monthly regulated flows during months in which regulated flows are less than EFS target. The column 8 shortages are the same for either the water rights or the control points.

$$\text{IFS}_{\text{month}} = \sum (\text{IFT}_{\text{day}}) - \text{RF}_{\text{month}}$$

Annual means for each year of the 78-year simulation of the daily EFS flow rate limits (targets) and associated shortages for water rights EFS-1 and EFS-2 are plotted in Figures 8.11 and 8.12. The annual means of daily target and shortages in Figures 8.11 and 8.12 were computed and plotted with *HEC-DSSVue* from the:

- monthly *SIMD* target and shortage rates in cfs from the datasets corresponding to columns 3 and 6 in Tables 8.29 and 8.30 and
- monthly *SIM* shortage rates corresponding to column 8 of Tables 8.29 and 8.30.

The blue solid line in Figures 8.11 and 8.12 are annual means converted to cfs of the monthly targets volumes in acre-feet/day read by the *SIM* simulation from the *TS* records in the input DSS file, which were derived from the monthly summation of daily targets computed in the *SIMD* daily simulation. The black dotted line is the annual means of the daily shortages computed in the *SIMD* daily simulation. The red dashed line is the annual volume of the monthly shortages computed in the *SIM* simulation.

Shortages in meeting subsistence and base flow targets represent deficits between targeted minimum flow limits and regulated stream flow. As previously discussed, the pulse flow components of the EFS incur no shortages in this example because the EFS are the most junior rights in the model. Otherwise, shortages can occur for pulse flow components of EFS due to the effects on regulated flows of other more junior water rights. The EFS high pulse flow component replicates regulated flow computed within the water rights priority sequence, which differs from the final regulated flow at the completion of the priority sequence. Even if the final regulated flows are employed is applying the optional *PF* record volume criterion, the computational procedure still generally allows daily shortages to occur in meeting high pulse flow targets in a daily *SIMD* simulation. This example is an exception due to the junior priority of the EFS.

Although simulation computations are performed with volumes in acre-feet, the frequency metrics in the tables and plots are expressed as mean daily and mean monthly flow rates in cfs to facilitate comparative analyses of the monthly versus daily simulation results. The mean, standard deviation, and quantities equaled or exceeded specified percentages of time were computed with *TABLES* with the default relative frequency option on the 2FRE and 6FRE records activated to employ Equation 7.1 (page 161) with N of 936 months or 28,490 days.

Frequency metrics for instream flow targets are tabulated in columns 2, 3, and 4 of Tables 8.22 and 8.23. The statistical metrics for the corresponding shortages are tabulated in columns 5, 6, 7, and 8. These statistics are for datasets from the previously described daily *SIMD* and monthly *SIM* simulations. Statistics for the 1940-2017 time series of monthly targets for EFS-1 and EFS-2, respectively, tabulated in Tables 8.29 and 8.30 are presented in columns 3 and 4 of Tables 8.22 and 8.23. Columns 3 and 4 are identically the same since the monthly targets from the daily *SIMD* simulation are input as *TS* record targets for the monthly *SIM* simulation.

The daily *SIMD* and monthly *SIM* simulations are related as follows. The daily targets (column 2) and corresponding shortages (column 5) are aggregated to monthly means (columns 3 and 6) within the daily *SIMD* simulation and included in the simulation results SUB, OUT, and DSS files. The monthly targets in the *SIMD* simulation results DSS file (column 3) are copied to the shared hydrology input DSS file (column 4) read as input by the *SIM* simulation.

Analyses of simulation results presented in the preceding Chapter 7 focus largely on reservoir storage contents and water supply reliabilities. Since the EFS of Chapter 8 are assigned the most junior priority (999999 in *IF* record field 5) in the WAM, reservoir storage contents and water supply reliabilities are not affected by addition of the EFS. The junior EFS do not affect the other more senior storage and diversion rights. However, reservoir storage contents and water supply reliabilities of the other water rights are affected by modifying the EFS right priorities to be more senior.

Discussion of Strategy for Combining Daily and Monthly Modeling Capabilities

The 2007 Senate Bill 3 (SB3) created a process for establishing environmental flow standards (EFS) and incorporating stream flow "*set asides*" in the Water Available Modeling (WAM) System to preserve the flows required by the EFS. The WAM system is appropriately and effectively based on a monthly computational time step. However, a daily time step is required to appropriately model the great within-month variability of stream flow, which has important effects on high pulse flow standards and to a lesser extent on subsistence and base flow standards. Daily modeling is also necessary to simulate the effects of reservoir flood control operations on stream flows and associated high pulse flow standards. The objective of the modeling strategy illustrated here is to combine *SIMD* daily simulation capabilities for setting environmental flow targets (SB3 set asides) with the advantages of employing monthly WAMs.

The proposed strategy begins with computing daily EFS targets in units of acre-feet/day in a daily *SIMD* simulation, which are summed to monthly totals in acre-feet/month within *SIMD* and included in the simulation results DSS output file. The monthly targets generated by the daily *SIMD* simulation are included in the *SIM* input dataset as time series *TS* records in the DSS input file, which are referenced by instream flow *IF* record water rights in the DAT input file.

The procedure for adopting monthly targets from a daily *SIMD* simulation as fixed input for a monthly *SIM* model is explored in this final section of Chapter 8. The monthly summation of daily targets from the daily *SIMD* simulation are replicated exactly in the monthly *SIM* model. However, daily *SIMD* shortages which depend on regulated flows as well as EFS targets are not necessarily closely replicated in the monthly *SIM* WAM.

Incorporating time series of monthly instream flow targets computed in a *SIMD* daily simulation into a monthly WAM input dataset is a valid modeling strategy that combines the strengths of both the daily and monthly modeling systems. A daily simulation provides the advantage of more accurate determinations of instream flow targets and corresponding shortages in meeting the targets. The strategy presented here transfers the enhanced accuracy of *SIMD*-based targets to a monthly WAM. The flow volumes for the EFS targets computed in the daily *SIMD* simulation are precisely preserved in the monthly WAM, resulting in a significantly improved SB3 process of WAM *set asides* of appropriated stream flow. However, the enhanced

accuracy of the *SIMD*-based daily shortages are not accurately preserved in the monthly WAM. Shortages are computed as the difference between targets and regulated flows. The monthly regulated flows in the *SIM* simulation do not capture within-month daily stream flow variability.

Differences in daily *SIMD* and monthly *SIM* simulations are driven primarily by stream flow variability. Within-month daily variability is very high for observed, naturalized, regulated, and unappropriated flows. Subsistence and base flow limits are prescribed on *ES* records for specified months and hydrologic conditions. In setting the instream flow target for each day of the *SIMD* simulation, the choice between the subsistence flow limit and the base flow limit depends upon the regulated flow for that day. High pulse flow events are engaged and daily targets are set based on replicating regulated flows. Shortages in meeting flow targets are highly dependent on regulated flows and daily fluctuations in regulated flows.

The timing of the effects on daily fluctuations in regulated flows resulting from reservoir storage refilling, reservoir releases, and water supply diversions and return flows are not precise. For example, inflows are passed through reservoirs in the model as required to protect downstream senior water rights. However, in real-world daily, hourly, and continuous reservoir operations, the timing of releases to pass inflows is not necessarily perfectly precise. Many of the diverse approximations related to smoothing (averaging) out flows and other variables in a monthly model are not modeled perfectly in a daily model either.

The validity of the *SIMD*-to-*SIM* instream flow target transfer strategy depends upon the purpose of the WRAP/WAM modeling application. The modeling strategy is weakest in applications focused on assessing capabilities for satisfying the instream flow targets. In this case, the inaccuracies in computing shortages in meeting the instream flow targets are important. Daily simulations are significantly more accurate than monthly simulations in evaluating reliabilities of meeting environmental instream flow standards or risks of failing to meet the environmental flow standards.

The *SIMD*-to-*SIM* instream flow target transfer strategy works best in applications focused on modeling the impacts of environmental flow standards on other water rights. For example, the strategy should work well for water availability/reliability evaluations for water right permit applications dealing with reservoir storage and diversion of water for municipal, industrial, and/or agricultural uses. The effects of the environmental flow standards on the proposed other water use is the focus.

CHAPTER 9

FREQUENCY ANALYSES OF ANNUAL SERIES FROM A DAILY SIMULATION

The results of a *SIM*, *SIMD*, or *SALT* simulation are viewed from the perspective of frequency, probability, percentage-of-time, and reliability metrics associated with stream flow, reservoir storage, water supply diversions, instream flow requirements, hydroelectric energy generation, salinity concentrations, and other variables. Statistical analyses are performed for time series variables from both simulation input datasets and simulation results. Methods and metrics for estimating and communicating likelihood are covered throughout the *Reference*, *Users*, *Fundamentals*, *Salinity*, and *Daily Manuals*. The present *Daily Manual* Chapter 9 begins with a brief overview summary of statistical frequency analysis methods covered elsewhere in the WRAP manuals before focusing on analyses of annual series derived from a daily model.

The six examples in Chapter 9 illustrate *TABLES*, *HEC-DSSVue*, and *HEC-SSP* statistical frequency analysis capabilities using the daily WAM dataset developed in Chapters 7 and 8. Examples 9.1 and 9.2 consist of compiling and analyzing annual series of minimum 7-day naturalized flow volumes. Examples 9.3, 9.4, 9.5, and 9.6 consist of flood frequency analyses of annual series of maximum end-of-day reservoir storage volumes. Alternative versions of the analyses are repeated employing *TABLES*, *HEC-DSSVue*, and *HEC-SSP* as follows.

Example 9.1: 7-day low flow frequency analysis using *TABLES* DATA and 6FRE records.

Example 9.2: 7-day low flow frequency analysis using *HEC-DSSVue*.

Example 9.3: Annual peak storage analysis with *TABLES* DATA and 6FRE records.

Example 9.4: Annual peak storage analysis with *SIMD* AFF file and *TABLES* 7FFA record.

Example 9.5: Annual peak storage analysis using *HEC-DSSVue*.

Example 9.6: Annual peak storage analysis using *HEC-SSP Statistical Software Package*.

Frequency analyses are applied to two different time series, the minimum 7-day mean flow rate in each year of the 1940-2017 period-of-analysis (Examples 9.1 and 9.2) and maximum end-of-day storage volume in each year (Examples 9.3-9.6). Annual 7-day low flow analyses are commonly associated with water quality and environmental flow studies. Frequency analyses of peak annual storage contents are employed in assessments of flood control capabilities of reservoirs. The two random variables adopted for the examples of Chapter 9 are of practical interest in typical modeling studies. The same frequency analysis computational procedures are applicable with any of the time series variables in the *SIMD* input dataset and simulation results.

Overview Summary of WRAP Frequency Analysis Capabilities

The WRAP modeling system is designed for assessing capabilities for achieving water management/use requirements under a defined scenario of water resources development and allocation during given sequences of naturalized (or other homogeneous condition) stream flows and reservoir evaporation-precipitation rates. The future is of concern, not the past. However, since future hydrology is unknown, historical past stream flows adjusted to remove non-stationarities (*IN* records) and reservoir evaporation-precipitation rates (*EV* records) are adopted as being statistically representative of the hydrologic characteristics of a river basin that can be expected to continue in the future. Stream flow, reservoir storage, and other variables are analyzed using statistical measures of likelihood such as exceedance frequency (or exceedance probability or percent-of-time) relationships, mean and standard deviation, and other metrics.

Table 9.1
Coverage of WRAP Frequency and Reliability Analyses Capabilities

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.

Appendix C Examples Illustrating *SIM* and *TABLES*

Basics of *TABLES* reliability and frequency analyses capabilities.

Users Manual

Chapter 5 Program *TABLES*

DSSM and DSSD Records – Daily or Monthly Data Read from DSS File

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

7DSS Record – Frequency Analyses of Annual Series Data

Fundamentals Manual

Example that employs basic *TABLES* frequency and reliability analyses.

Daily Manual

Chapters 7 and 8 examples include basic frequency and reliability analyses.

Chapter 9 examples focus on analyses of annual series from a daily simulation.

Appendix A Program *Daily Flows*

FREQ Record – Flow Frequency Analysis

REGCOR Record – Regression and Correlation Analyses

Salinity Manual

8FRE, 8FRQ Records – Frequency Analysis of Salinity Loads and Concentrations

8REL Record – Water Supply Reliability Constrained by Salinity

Statistical Analysis Software

Statistical analysis methods are covered throughout the WRAP manuals as outlined in Table 9.1. Chapter 7 of the *Reference Manual* [1] and Chapter 5 of the *Users Manual* [2] describe capabilities provided by the WRAP program *TABLES*, including explanations of reliability and frequency analysis concepts and methods incorporated in *TABLES*. The basic methodologies 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.

WRAP applications of *HEC-DSSVue* [7] are described in Chapter 6 of the *WRAP Users Manual*. *HEC-DSSVue* is a comprehensive time series data management software package that includes a general statistical analysis component designed for general applications of standard statistics and probability methods. The *HEC-SSP Statistical Software Package* [20] is also available from the USACE Hydrologic Engineering Center (HEC). *HEC-SSP* is designed specifically for detailed flood flow frequency analyses and is the standard Hydrologic Engineering Center software for flood flow frequency studies. *HEC-SSP* also performs various other types of statistical analyses. *HEC-SSP* replicates the general statistical analyses provided by *HEC-DSSVue* and includes other more comprehensive options for detailed flood flow frequency analysis.

Some of the basic statistical analysis methods are the same in both *TABLES* and *HEC-DSSVue*. Each program provides certain analysis options not provided by the other. For example, both programs create frequency tables, but *HEC-DSSVue* also creates frequency plots. *TABLES* creates tables of water supply reliability metrics that are not available in *HEC-DSSVue*. The frequency analyses in Chapter 9 are repeated with both *HEC-DSSVue* and *TABLES* to comparatively illustrate similarities and differences of the two software systems. Basic statistical methods shared by these two programs are covered in many textbooks [9, 10] and other publications. Differences in organization and analysis capabilities of the two alternative data management systems and their statistical analysis components are also evident in this chapter.

The Chapter 9 examples illustrate capabilities of *TABLES*, *HEC-DSSVue*, and *HEC-SSP*. Other software packages not employed in the examples are also available for performing statistical analyses in conjunction with WRAP simulation studies. The *Indicators of Hydrologic Alteration (IHA)* available from the Nature Conservancy [19] provides additional capabilities that may be applied with WRAP in environmental flow studies. *IHA* as well as HEC and WRAP programs employ DSS files. *IHA* computes an array of statistics for daily stream flows designed for environmental instream flow studies and associated assessments of changes in stream flow characteristics over time. Microsoft Excel provides a variety of capabilities that are useful with WRAP, including basic statistical analysis capabilities. The Hydrology-based Environmental Flow Regime (HEFR) is a Microsoft Excel spreadsheet based statistical analysis tool that computes metrics that are similar to the IHA statistics. HEFR tools are available at the TCEQ website: https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/eflows/resources.html

Frequency Analysis Methods

The terms "*frequency*" and "*probability*" are used here interchangeably. Whereas probability is a dimensionless number between 0.0 and 1.0, exceedance and cumulative frequencies are usually expressed as a percentage between 0.0 and 100 percent. These metrics are expressions of likelihood

or percent-of-time. Exceedance probability (or frequency) is related to cumulative probability (or frequency) as follows: exceedance probability = 1.0 – cumulative probability

Two general approaches are employed in developing frequency relationships: (1) relative frequency and (2) probability distribution functions. Relative frequency is expressed alternatively by Eq. 9.1 or Eq. 9.2, where m is the rank and N is the sample size. In WRAP applications the sample size N is the number of days, months, or other time intervals in the period-of-analysis and the rank m is the number of periods during the simulation that a particular flow or storage amount is equaled or exceeded. Equation 9.2 is commonly called the Weibull formula.

$$\text{Exceedance Frequency} = \frac{m}{N} (100\%) \quad (9.1)$$

$$\text{Exceedance Frequency} = \frac{m}{N+1} (100\%) \quad (9.2)$$

TABLES includes options for both Equations 9.1 and 9.2. *HEC-DSSVue* and *HEC-SSP* employ the alternative Equation 9.2. For analyses of 1940-2017 monthly time series with 936 monthly quantities, the smallest quantity in the dataset will be assigned exceedance frequencies of 100.00% and 99.893% by Equations 9.1 and 9.2, respectively. For analyses of 1940-2017 annual time series with 78 annual quantities, the smallest quantity in the dataset will be assigned exceedance frequencies of 100.00% and 98.734% by Equations 9.1 and 9.2, respectively. The primary reason that that N is replaced with $N+1$ in the Weibull formula (Eq. 9.2) is to prevent assigning an exceedance frequency of 100.00 percent. Conceptually, the smallest value in a dataset of sample size of 936 months, 78 years, 28,490 days or any other fixed number should have less than a one hundred percent chance of being equaled or exceeded. Generally, Eq. 9.2 is associated with flood frequency analyses, and Eq. 9.1 is a more general expression of relative frequency.

Alternatively, *HEC-DSSVue*, *HEC-SSP*, and the *TABLES* 2FRE and 6FRE records include options to apply the normal (Eq. 9.3) or log-normal (Eq. 9.4) probability distribution to the series of flow and storage amounts generated by *SIM* or *SIMD* or adjustments thereto.

$$X = \bar{X} + z S \quad (9.3)$$

$$\log X = \overline{\log X} + z S_{\log X} \quad (9.4)$$

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. 9.3 expressed as Eq. 9.4 with z still derived from the normal probability distribution. Frequency factors (z) for selected exceedance probabilities are tabulated in Table 9.2.

HEC-DSSVue, *HEC-SSP*, and the *TABLES* 7FFA record also apply the log-Pearson type III probability distribution in a standard manner [9]. The frequency factor z in Eq. 9.4 is a function of the skew coefficient for the log-Pearson type III probability distribution. A frequency factor table is provided as Table 7.18 in the *Reference Manual*. With a skew coefficient of zero, the log-Pearson type III distribution is the same as the log-normal distribution.

The mean \bar{X} and standard deviation S computed from the data using Equations 9.5 and 9.6 are the parameters used to model a frequency relationship based on the normal probability distribution using Eq. 9.3. For the log-normal distribution, the mean and standard deviation of the logarithms of the data are computed and entered into Equation 9.4. The log-Pearson type III probability distribution also employs Equation 9.4 with the mean and standard deviation of the logarithms of the data, but the frequency factor z is a function of the skew coefficient G (Eq. 9.7). However, with a G of 0.00, the frequency factors in Table 9.2 are applicable to the log-Pearson type III as well as normal and log-normal probability distributions.

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i \quad (9.5)$$

$$S = \left[\frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2 \right]^{0.5} \quad (9.6)$$

$$G = \frac{n \sum_{i=1}^n (X_i - \bar{X})^3}{(n-1)(n-2) S^3} \quad (9.7)$$

Table 9.2
Frequency Factors for the Normal Probability Distribution

Exceedance Frequency	Factor z in Eqs. 9.3 & 9.4	Exceedance Frequency	Factor z in Eqs. 9.3 & 9.4
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		

The choice between applying the concept of relative frequency directly using Eq. 9.1 or Eq. 9.2 versus adopting the normal (Eq. 9.3), log-normal (Eq. 9.4), or log-Pearson Type III (Eq. 9.4) probability distributions depends upon the particular variable, sample size, and application. A discussion of considerations in choosing between alternative methods is found in Chapter 7 of the *Reference Manual*. If a probability distribution function is employed, different random variables may be more appropriately modeled with different probability distribution functions.

SIMD Input and Output Datasets Used in the Chapter 9 Examples

Many examples of frequency analyses are found in the *Reference* and *Fundamentals Manuals* and the preceding chapters of this *Daily Manual*. The statistical frequency analyses in all of these other examples are performed directly for time series datasets of monthly or daily quantities. The Chapter 9 examples employ annual series derived from daily datasets.

The Chapter 9 examples begin with one of the following two alternative datasets.

1. Daily naturalized flow volumes at specified control points in acre-feet/day stored in the *SIMD* input file with filename ExamplesHYD.DSS and also found in the *SIMD* simulation results SUB and DSS files (Examples 9.1 and 9.2).
2. Daily end-of-day reservoir storage volumes at specified control points in acre-feet found in the *SIMD* simulation results SUB and DSS files (Examples 9.3, 9.4, 9.5, 9.6).

These time series datasets contain 28,490 daily quantities covering each day of the 1940-2017 hydrologic period-of-analysis. Frequency analyses of these datasets are presented in the preceding Chapters 7 and 8 and are not repeated here.

The statistical analyses presented in Chapter 9 are for the following annual time series. Each contains 78 quantities derived from the 28,490-day long daily series described above.

1. The minimum mean flow rates in acre-feet/day during any period of seven consecutive days (commonly called 7-day low flows) for naturalized flow at specified sites occurring in each of the 78 years of the 1940-2017 period-of-analysis.
2. The maximum end-of-day reservoir storage contents in acre-feet at specified control points occurring during each of the 78 years of the 1940-2017 period-of-analysis.

The daily WAM of Chapters 7, 8, and 9 includes the *SIMD* input dataset of Tables 7.3, 7.4, and 8.4 and the output files described in Chapters 7 and 8. The daily WAM providing data for the Chapter 9 statistical analysis examples consists of the final DAT, DIF, and DSS input files from Chapter 8. The input and output files are controlled by the following group of records from the *SIMD* input DAT file of Table 7.3 with revisions for individual examples.

JD	78	1940		1	0	0		7		20
JO	6				1					
JT	0	0	0	0	1					
JU	0	0	0	2	2					
OF	0	0	3	0						
DF		Whit	WacoG	High	Belton	Grang	Camer	Hemp	Examples	

Daily variables are recorded in the *SIMD* output SUB and DSS files for relevant control points. Daily naturalized flows at relevant control points are read from the hydrology input DSS file.

Examples 9.1 and 9.2 consist of analyses of daily naturalized stream flows which are the same in all variations of the WAMs in Chapters 7 and 8. Examples 9.3, 9.4, 9.5, and 9.6 consist of analyses of the end-of-day reservoir storage contents from the simulation results of the final daily WAM dataset developed in Chapter 8.

Example 9.1 – Low Flow Frequency Analysis with TABLES DATA and 6FRE Records

The TABLES TIN file input DATA record described in the *Users Manual* controls a set of options manipulating data from SIMD or SIM output SUB or OUT files to develop another data array of interest that can then be accessed by the operations controlled by other TABLES input records. Although also applicable to simulation results from a monthly SIM simulation, the DATA record is motivated largely by applications in analyzing stream flows from a daily WAM.

DATA and 6FRE records are employed here to develop low-flow frequency metrics for annual minimum 7-day mean naturalized flow rates in units of acre-feet/day. The DATA record provides capabilities for developing an annual series of minimum 7-day mean flows. Frequency analyses are performed with 6FRE records, the daily equivalent of the monthly 2FRE record.

The TIN file in Table 9.3 begins with a DATA record. 6NAT in DATA record field 2 means that daily naturalized flows are read from a SUB file generated by SIMD. Option 1 in column 20 of the DATA record of Table 9.2 indicates that an annual data array is created. Entries in columns 24 and 28 specify 7-day moving averages. Option 2 in column 32 means the minimum of the 365 or 366 seven-day volumes in each year is adopted. The two 6FRE records in the TIN file illustrate two alternative methods (relative frequency versus log-normal probability distribution) for performing the frequency analysis of the data provided by the DATA record.

Table 9.3
TABLES Input TIN File for Example 9.1

```

**          1          2          3          4          5
** 5678901234567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !      !      !
DATA6NAT  0    0    1    1    7    2                                1
6FRE    1    0    0    2    0
6FRE    1    0    0    2    2
ENDF

```

In accordance with the DATA record in the TIN file of Table 9.3, the TABLES routines governed by the DATA record:

- read the 28,490 daily naturalized flows at each of the eleven control points from the SIMD output SUB file,
- compute 28,490 seven-day moving averages, and
- record the minimum of the 365 or 366 seven-day moving totals in each of the 78 years in an array which is accessed by the 6FRE records.

The 7-day moving averages are the average of daily flow volumes for the current day and six preceding days. Since seven days are required for 7-day summation, the first six days of the first year (1940) are not considered in the selection of the minimum 7-day volume for 1940. The DATA record produces annual series for each of the 11 control points consisting of the minimum 7-day mean daily volume (flow rate) of naturalized flow in acre-feet/day in each of the 78 years of the simulation tabulated in Table 9.4. The TABLES input TIN file of Table 9.3 generates the output TOU file of Table 9.4.

Table 9.4
TABLES Output TOU File for 7-Day Low Flow Frequency Analysis of Example 9.1
7-Day Low Flow Tabulation, Relative Frequency Table, Log-Normal Frequency Table

DATA RECORD VARIABLE GNAT ANNUAL SERIES DATASET

YEAR	HK	Whit	WacoL	WacoG	High	Belton	George	Grang	Carrer	Bryan	Hemp
1940	7.61	27.21	0.00	12.84	45.03	8.35	4.33	13.93	82.55	294.43	359.88
1941	77.49	458.40	23.61	1231.77	1497.23	341.20	27.72	89.18	728.11	2545.29	2705.63
1942	179.57	326.52	90.13	608.04	710.50	210.24	7.20	23.14	437.05	1481.65	1686.77
1943	2.82	36.44	9.72	69.33	166.79	15.19	2.74	8.82	109.79	355.39	737.17
1944	13.87	180.75	6.07	177.24	286.99	111.66	3.09	9.92	354.78	648.40	1170.45
1945	28.73	268.16	28.30	367.91	428.24	90.33	16.83	54.15	353.44	542.91	2299.77
1946	35.48	221.03	0.00	300.66	511.94	82.70	12.01	38.68	338.06	1565.35	2248.87
1947	62.83	286.69	0.00	82.28	113.62	7.47	9.40	30.22	116.56	307.64	839.21
1948	44.84	101.29	0.00	154.70	160.62	0.00	2.72	8.76	24.38	220.16	185.18
1949	40.30	120.84	0.00	134.38	174.09	0.00	2.58	8.33	33.29	317.11	541.14
1950	16.02	94.13	0.00	138.39	147.42	0.00	4.24	13.66	49.02	186.75	496.26
1951	0.00	28.45	0.00	41.01	71.89	0.00	1.14	3.67	3.92	84.36	157.34
1952	1.77	0.00	0.00	24.77	57.69	0.00	2.20	7.09	0.00	107.75	257.95
1953	0.00	0.00	0.00	8.01	156.98	0.00	1.12	3.62	23.07	378.20	676.68
1954	0.00	0.00	0.00	9.26	44.19	0.00	0.00	0.00	0.00	139.08	308.96
1955	18.18	3.94	0.00	15.64	53.82	0.00	0.00	0.00	6.88	178.01	386.69
1956	0.00	22.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.87
1957	0.00	66.52	0.00	75.05	72.20	4.13	3.35	10.79	28.99	31.87	84.37
1958	0.00	83.21	24.15	106.02	283.53	15.72	23.54	75.73	295.95	834.76	1244.77
1959	1.48	38.44	2.55	161.30	287.23	9.77	18.41	59.23	133.06	456.73	906.32
1960	0.00	92.06	0.50	83.91	140.49	1.79	8.32	26.82	79.62	303.99	428.57
1961	110.02	440.24	0.00	572.18	789.82	0.00	33.78	108.69	681.35	1034.89	2309.44
1962	35.36	115.19	2.79	303.38	377.94	4.63	8.47	27.29	68.84	452.62	476.67
1963	0.00	22.08	0.00	0.00	28.69	5.69	1.31	4.24	13.10	161.51	342.97
1964	47.49	56.68	0.11	92.37	122.59	1.82	0.64	2.07	19.45	234.25	402.06
1965	61.23	222.07	0.05	331.24	532.04	0.11	17.34	63.38	288.82	1089.29	999.87
1966	7.38	100.31	12.20	296.58	286.22	27.12	21.63	96.13	383.87	927.74	1345.05
1967	1.39	71.11	0.24	345.60	442.24	0.16	1.60	3.85	28.69	785.62	796.65
1968	0.00	132.16	95.87	277.63	468.86	53.30	6.69	91.93	286.80	649.65	1565.12
1969	6.58	150.65	8.81	203.91	214.19	5.10	15.62	65.70	203.69	1355.35	1554.62
1970	0.00	34.37	0.00	52.31	92.32	0.00	3.37	64.53	276.64	556.83	1193.16
1971	0.64	13.59	4.32	88.86	99.34	6.20	0.23	0.70	25.69	350.18	436.30
1972	27.22	98.54	55.27	82.87	107.07	0.00	0.61	12.27	37.19	468.98	489.89
1973	0.00	52.71	0.66	133.65	273.82	20.23	5.63	74.74	93.10	636.24	811.77
1974	15.00	67.69	1.81	92.48	260.79	7.70	9.98	55.65	161.40	652.34	861.94
1975	27.56	7.12	13.45	73.62	178.36	0.00	14.63	97.78	275.26	621.60	1007.60
1976	41.62	91.67	14.86	171.95	548.73	12.15	10.07	71.99	279.45	959.48	1317.87
1977	0.00	0.00	0.00	44.58	172.40	0.00	1.78	29.17	68.92	357.27	627.32
1978	6.15	20.81	0.00	58.27	154.93	6.42	0.08	0.00	1.49	226.34	336.90
1979	0.00	19.06	28.03	0.00	17.88	0.00	4.23	70.79	200.01	313.90	909.72
1980	11.60	72.27	0.13	36.13	214.59	0.00	0.45	0.00	42.95	479.86	659.37
1981	16.47	41.82	0.00	49.00	239.27	0.00	2.82	0.00	172.71	650.05	1102.85
1982	14.42	0.00	1.14	105.34	250.88	0.00	0.00	0.00	6.94	377.51	625.12
1983	0.00	0.00	1.07	25.21	58.00	0.00	0.00	5.95	63.06	284.58	1040.95
1984	0.00	0.00	0.00	33.20	89.29	0.00	0.00	0.00	0.51	148.07	412.26
1985	8.61	188.34	3.72	259.24	189.45	6.37	0.00	0.00	14.19	498.20	537.82
1986	79.00	132.46	0.00	518.57	527.64	49.98	0.00	4.40	431.05	1538.09	2218.10
1987	11.17	15.98	0.00	0.00	77.23	28.35	0.77	28.08	297.35	751.09	1183.71
1988	7.92	0.00	0.00	13.06	138.10	2.30	0.00	0.00	23.49	272.14	377.88
1989	18.15	64.22	0.00	107.71	220.97	0.00	0.00	0.00	11.96	345.20	579.45
1990	50.18	82.52	0.00	334.05	484.17	8.10	0.00	0.00	48.68	832.31	1380.58
1991	180.36	230.49	40.99	761.08	846.61	19.73	2.29	10.67	165.65	1789.78	2646.35
1992	52.68	116.27	0.00	277.40	512.85	46.05	0.75	23.96	333.32	1478.03	2246.08
1993	40.60	142.93	0.00	227.58	510.98	36.99	0.20	17.87	153.92	1036.97	1486.62
1994	19.91	61.51	0.00	0.00	296.32	55.48	1.87	0.00	91.65	359.84	1112.43
1995	40.29	216.67	0.00	189.19	344.55	162.46	0.00	10.01	81.65	563.95	1309.36
1996	29.15	42.95	0.00	103.00	252.87	15.39	0.80	0.00	131.41	566.50	793.41
1997	0.00	32.70	0.00	221.35	325.87	45.72	0.00	39.97	233.28	577.68	1345.47
1998	0.00	2.10	0.00	136.75	273.59	51.02	0.00	11.34	232.49	366.48	790.29
1999	0.00	0.00	0.00	0.00	42.46	0.00	0.00	5.04	40.76	46.65	345.71
2000	0.00	61.22	0.00	47.58	38.55	0.00	0.17	0.00	0.00	30.05	2.17
2001	0.00	48.68	72.13	45.47	190.11	51.49	1.15	15.00	298.55	1815.32	2020.77
2002	0.00	57.22	0.00	44.79	163.67	0.00	1.84	13.32	298.25	715.84	1224.91

2003	0.00	1.82	0.00	74.22	118.56	0.00	0.00	0.00	137.65	334.62	830.01
2004	0.00	17.64	0.00	92.13	242.10	48.31	0.00	11.72	265.85	992.55	2193.44
2005	19.33	79.54	0.00	130.62	324.04	17.10	1.10	9.03	234.22	848.53	1283.60
2006	11.66	59.73	0.00	30.06	87.40	0.00	0.00	0.00	59.76	210.95	274.85
2007	34.43	79.36	45.75	68.92	324.70	59.15	0.00	11.07	731.13	1579.60	2732.76
2008	4.24	9.06	4.09	35.22	108.12	0.00	0.00	0.00	60.27	430.68	735.52
2009	4.98	41.52	2.67	65.67	145.36	8.65	0.75	0.00	50.68	455.30	755.65
2010	40.81	126.76	31.56	400.85	656.53	10.58	0.00	5.30	221.73	1336.81	1751.05
2011	3.50	39.37	0.08	0.00	9.78	0.00	2.50	0.00	4.59	89.76	133.16
2012	0.00	0.59	1.09	0.00	0.00	0.00	0.00	4.20	53.83	128.82	329.38
2013	0.00	0.00	0.00	41.21	43.57	4.76	0.00	0.00	52.72	174.59	163.77
2014	0.00	18.86	1.15	25.30	8.04	0.40	0.00	0.00	0.00	0.53	86.21
2015	9.80	32.59	1.64	51.12	145.93	25.80	0.00	12.87	291.78	631.78	1039.52
2016	0.00	24.54	0.00	154.26	134.08	0.00	0.00	0.00	27.99	547.70	952.21
2017	0.00	105.39	0.00	260.67	382.98	0.00	0.00	0.00	54.61	752.39	1050.07

VARIABLE 6NAT IN DATA RECORD DATASET

Daily Data from January 1940 through December 2017

DATA Record Parameters DR(1-10) 0 0 1 1 7 2 1 1 12 31

CP	EK	Whit	WacoL	WacoG	High	Belton	George	Grang	Carer	Bryan	Hemp
Mean	20.87	82.30	8.09	153.72	251.26	23.12	4.18	21.36	154.01	600.68	965.10
Std Dev	34.39	95.06	19.34	196.68	238.14	51.32	7.03	29.27	167.14	497.74	687.73
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17
99%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	14.41
98%	0.00	0.00	0.00	0.00	4.50	0.00	0.00	0.00	0.00	17.06	55.11
95%	0.00	0.00	0.00	0.00	17.07	0.00	0.00	0.00	0.00	45.17	128.47
90%	0.00	0.00	0.00	6.41	43.34	0.00	0.00	0.00	4.46	124.61	243.39
80%	0.00	11.78	0.00	28.16	75.21	0.00	0.00	0.00	23.32	216.48	370.68
70%	0.00	23.16	0.00	45.06	115.60	0.00	0.00	0.28	38.62	310.14	492.44
60%	1.98	38.62	0.00	69.00	148.92	0.12	0.48	4.53	55.64	361.17	688.45
50%	7.61	57.22	0.00	88.86	178.36	4.76	1.12	9.03	82.55	468.98	830.01
40%	14.31	72.04	0.45	126.03	249.13	8.02	2.13	12.16	150.66	575.45	1033.14
30%	24.30	96.78	2.25	167.69	287.13	15.59	3.25	23.63	232.96	690.44	1212.21
20%	40.30	128.92	9.18	267.36	401.08	40.48	7.65	45.64	290.00	940.44	1422.99
10%	54.39	221.24	28.96	350.06	528.52	56.22	15.86	72.54	353.71	1478.75	2223.70
Maximum	180.36	458.40	95.87	1231.77	1497.23	341.20	33.78	108.69	731.13	2545.29	2732.76

VARIABLE 6NAT IN DATA RECORD DATASET

Daily Data from January 1940 through December 2017

DATA Record Parameters DR(1-10) 0 0 1 1 7 2 1 1 12 31

CP	EK	Whit	WacoL	WacoG	High	Belton	George	Grang	Carer	Bryan	Hemp
Mean	20.87	82.30	8.09	153.72	251.26	23.12	4.18	21.36	154.01	600.68	965.10
Std Dev	34.39	95.06	19.34	196.68	238.14	51.32	7.03	29.27	167.14	497.74	687.73
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17
99%	0.00	0.01	0.00	0.04	1.87	0.00	0.00	0.00	0.10	7.02	50.08
98%	0.00	0.03	0.00	0.08	3.09	0.00	0.00	0.00	0.21	11.11	67.85
95%	0.00	0.11	0.00	0.28	6.54	0.00	0.00	0.00	0.61	22.09	107.01
90%	0.01	0.33	0.00	0.85	12.75	0.01	0.01	0.02	1.58	40.70	160.42
80%	0.05	1.30	0.01	3.16	28.61	0.03	0.03	0.08	5.02	85.30	261.92
70%	0.17	3.50	0.03	8.16	51.24	0.11	0.09	0.27	11.56	145.43	372.98
60%	0.47	8.15	0.07	18.36	84.31	0.30	0.19	0.71	23.59	229.42	504.50
50%	1.20	17.98	0.16	39.20	134.29	0.78	0.40	1.76	45.94	351.30	669.06
40%	3.10	39.68	0.38	83.69	213.88	2.05	0.85	4.37	89.49	537.93	887.31
30%	8.54	92.52	0.94	188.40	351.91	5.74	1.89	11.60	182.61	848.58	1200.18
20%	27.98	249.20	2.71	486.97	630.26	19.13	4.79	36.36	420.80	1446.73	1709.08
10%	145.06	984.78	11.83	1817.56	1414.25	101.56	17.48	177.18	1339.29	3031.91	2790.41
Maximum	180.36	458.40	95.87	1231.77	1497.23	341.20	33.78	108.69	731.13	2545.29	2732.76

The main purpose of the DATA record is to create a data array that is stored in computer memory to be accessed by any number of frequency and time series records that follow in the TIN file. However, the array can also be written in the TOU file. The first table in the TOU output file of Table 9.4 is an optional tabulation of the annual data series array activated by option 1 entered in column 52 of the DATA record. The quantities in the tables of Table 9.4 are

the minimum mean naturalized flow rate over any seven consecutive days of each year at the eleven control points in units of acre-feet/day. Any other alternative units such as cubic feet per second (cfs) could be easily adopted by changing input parameters on the DATA record.

Option 1 selected in DATA record column 24 specifies moving averages over the 7 days specified in column 28. The total volumes over 7 days are divided by 7 to obtain means. If option 1 *moving average* is changed to option 2 *moving totals*, the quantities are 7.0 times larger.

The two frequency tables in Table 9.4 were created with the two 6FRE records in Table 9.3 using the eleven 78-year annual series created with the DATA record and recorded as the first table in Table 9.4. The 6FRE record routines read these data from arrays in computer memory. Only one 6FRE record is necessary. However, the two 6FRE records are included in this example to compare the alternative relative frequency versus probability function options.

The frequency tables in Table 9.4 begin with the mean, standard deviation, and minimum of the 78 minimum annual 7-day naturalized flow rates in acre-feet/day. The maximum flow volume tabulated in the last row of the two 6FRE frequency tables of Table 9.4 is the largest of the 78 amounts listed in the first table of Table 9.4 which is created by the DATA record. The minimum 7-day flow rates exceeded during specified percentages of the 78 years are tabulated based on relative frequency counting in the first frequency table. For the second frequency table, the quantities associated with the specified exceedance frequencies are computed based on applying the Gaussian normal probability function to the logarithms of the flow rates.

Interpretation of the quantities in the frequency tables are illustrated as follows by referring to the first frequency table in the TOU file of Table 9.4. The minimum 7-day mean naturalized flow rate at control point Hemp exceeds 830.0 acre-feet/day during 50% of the 78 years of the 1940-2017 hydrologic period-of-analysis. Thus, the 50% exceedance frequency (median) annual minimum 7-day average flow rate is 830.0 acre-feet/day. The probability or chance of the minimum flow during any 7 consecutive days of any year exceeding 830.0 acre-feet/day is estimated to be 0.50. An average flow of 830.0 acre-feet/day during seven days is equivalent to 418.5 cubic feet/second (cfs) or a total 7-day volume of 5,810 acre-feet.

Parameter METHOD in 6FRE record field 6 provides three options for performing frequency analyses which are described in the *Reference Manual*: (1) relative frequency based on Eq. 9.1, (2) log-normal probability distribution based on Eq. 9.4, and (3) normal distribution based on Eq. 9.3. Options 1 and 2 are selected on the two 6FRE records in the TIN file replicated as Table 9.3. The first frequency table in the TOU file of Table 9.4 is based on relative frequency (Eq. 9.1). The second frequency table is based on the log-normal distribution (Eq. 9.4).

With either the relative frequency or probability distribution options activated on the 6FRE record, the mean and standard deviation of the annual time series shown in the frequency tables are computed with Eqs. 9.5 and 9.6 with an N of 78 years. The quantities associated with the specified exceedance frequencies are computed with Eq. 9.1, again with N of 78 years, for the relative frequency version of the analysis shown in the first frequency table. In the second frequency table, the quantities associated with the specified exceedance frequencies are computed with Eq. 9.4, with the mean and standard deviation of the logarithms of the 78 quantities. The frequency factor z in Eq. 9.4 is from Table 9.2.

Flow frequency metrics at four of the control points computed based on relative frequency versus the log-normal probability distribution are compared in Table 9.5. The two alternative computational methodologies produce very different results. The selection between the two alternative frequency analysis approaches depends on further exploration of whether the log-normal probability function accurately models the random variable being considered, in this case the minimum annual 7-day mean flow rate.

Table 9.5
Comparison of Results Based on Relative Frequency Versus Log-Normal Probability

Control Point	Exceedance Frequency	Relative Frequency (ac-ft/day)	Log-Normal Probability (ac-ft/day)
Cameron Gage (Camer)	90%	4.46	1.58
	50%	82.55	45.94
	10%	353.7	1,339
Highbanks Gage (High)	90%	43.34	12.75
	50%	178.4	134.3
	10%	528.5	1,414
Bryan Gage (Bryan)	90%	124.6	40.70
	50%	469.0	351.3
	10%	1,479	3,032
Hempstead Gage (Hemp)	90%	243.4	160.4
	50%	830.0	669.1
	10%	2,224	2,790

The frequency analyses presented in the preceding Chapters 7 and 8 of this *Reference Manual* and in the other WRAP manuals employ the relative frequency formula (Eq. 9.1) with a sample size N of either 936 months or 28,490 days. The relative frequency methodology is considered to provide a reasonably accurate probability estimates for a large sample size. No premise is required regarding appropriate probability distribution function when applying Equation 9.1. Relative frequency results are simple to interpret and understand.

Annual frequency analyses in Chapter 9 are based on a sample size N of 78 years, which is much smaller than other examples with N of 936 or 28,490. The accuracy of the probability estimates could possibly be improved by switching to the log-normal probability distribution option. However, the accuracy of the analysis then depends upon how closely the log-normal probability distribution function models the random variable (minimum annual 7-day mean flow rate). The log-normal distribution is commonly adopted for modeling hydrologic variables. One key reason that the log-normal distribution is typically considered better than the normal distribution for hydrologic variables such as stream flow is that probabilities of zero are assigned for negative flows. The normal distribution allows non-zero positive probabilities for negative flows. Probability plots developed with *HEC-DSSVue* or *HEC-SSP* may be used to visualize the closeness-of-fit of alternative probability distributions for a random variable of interest.

Example 9.2 – Low Flow Frequency Analysis with *HEC-DSSVue*

Example 9.2 performs basically the same computations as Example 9.1, but *HEC-DSSVue* is employed rather than *TABLES*. Low flow frequency analyses provide useful information for environmental flow studies, water quality studies, and other water resources planning and management activities. The low flow analyses repeated in Examples 9.1 and 9.2 illustrate fundamental standard statistics and probability methods generally applicable for a broad range of other random variables and analysis purposes.

Basic statistical analysis methods are applied in Examples 9.1 and 9.2 to a random variable defined as the minimum mean flow rate in acre-feet/day occurring during any seven consecutive days of each year. The original daily naturalized flow dataset adopted for the analyses are obtained from either the *SIMD* time series input DSS file or *SIMD* simulation results output SUB or DSS files. The two examples and two alternative data management and analysis software systems are compared as follows.

- Both Examples 9.1 and 9.2 explore daily naturalized flows. The same *TABLES* and *HEC-DSSVue* routines can be applied to any of the daily or monthly time series in the WAM input and output files. *TABLES* both reads and writes DSS files. The basic statistical methods are generally applicable regardless of the random variable being analyzed.
- Both examples adopt annual series of minimum 7-day quantities. The same *TABLES* and *HEC-DSSVue* routines can be applied to time series datasets defined by any other time periods such as annual series of 1-day, 3-day, 14-day, 30-day amounts or monthly series of 1-day, 5-day, or 7-day amounts.
- The *HEC-DSSVue* and *TABLES* procedures are applicable to either maxima or minima.
- Both examples adopt annual series of 7-day moving averages of flow rates in acre-feet/day but could alternatively use moving totals of 7-day flow volumes in acre-feet.
- Although the *SIMD* simulation computations are performed with units of acre-feet/day, unit conversions within *HEC-DSSVue* and *TABLES* allow any other units such as cubic feet per second (cfs) or cubic meters per second (m³/s) to be adopted for the statistical analyses.
- *HEC-DSSVue* and *TABLES* include some of the same basic statistical techniques. Both programs also include some statistical analysis capabilities that are not available in the other.
- *HEC-DSSVue* and *TABLES* provide very different frameworks and logistical mechanics for managing time series datasets.

For brevity, only five control points are adopted in Example 9.2. The methodology can be applied to datasets containing any number of control points. Naturalized flows are read from the DSS records of the Chapter 8 WAM for control points Belton, Camer, WacoG, High, and Hemp at gaging stations (Table 7.1) on the Leon River near Belton, Little River at Cameron, Brazos River near Waco, Brazos River near Highbank, and Brazos River near Hempstead. The daily time series plots of Figures 9.1 through 9.5 display the extreme variability that is characteristic of river flows. The plot scale required to include the full range from zero flow to very large flood peaks result in low flow fluctuations being somewhat hidden in the plots. Due to relative scale, floods are more clearly visible in the plots than low flow variability.

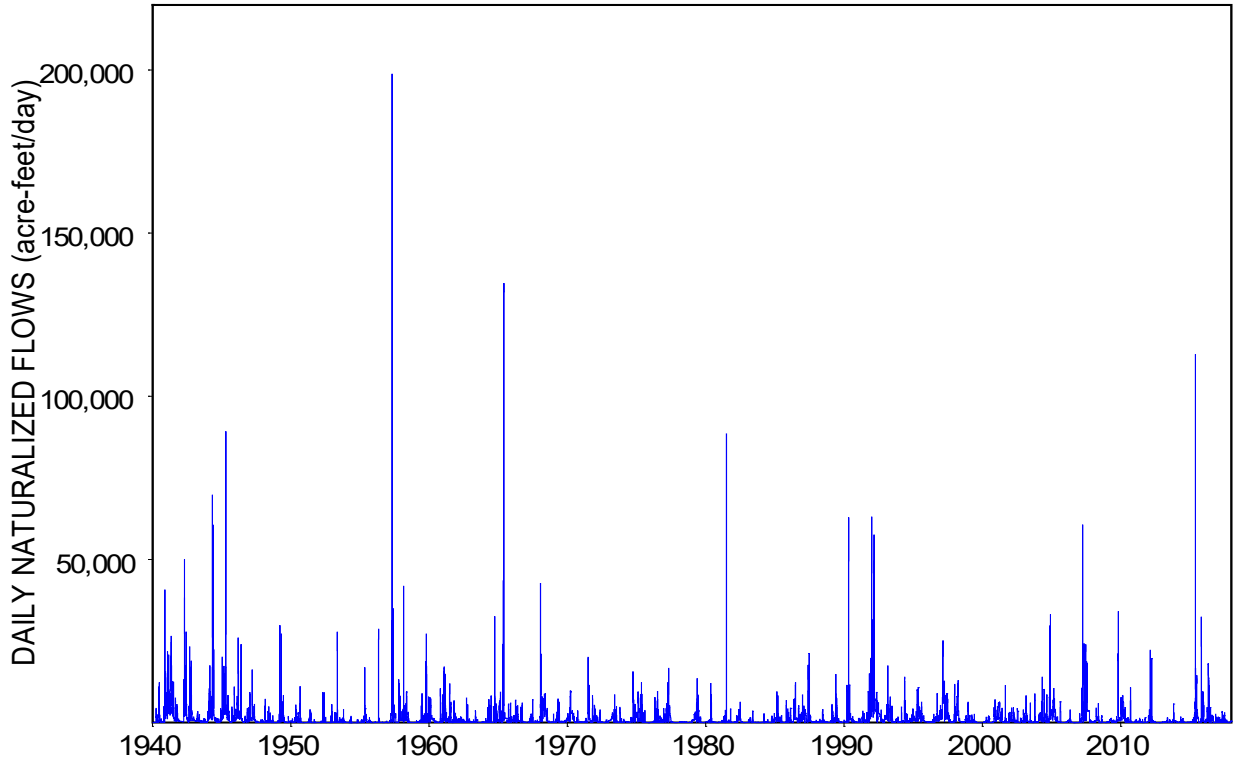


Figure 9.1 Daily Naturalized Flows at Control Point Belton

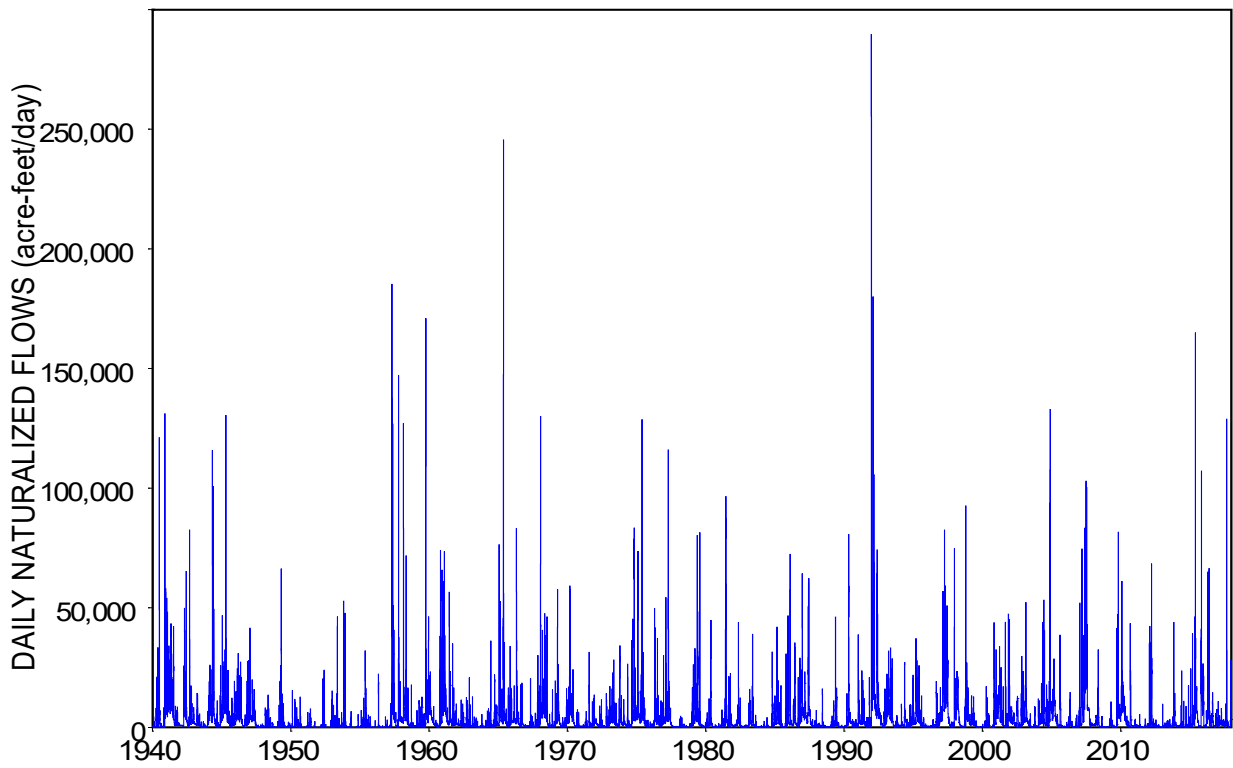


Figure 9.2 Daily Naturalized Flows at Control Point Camer

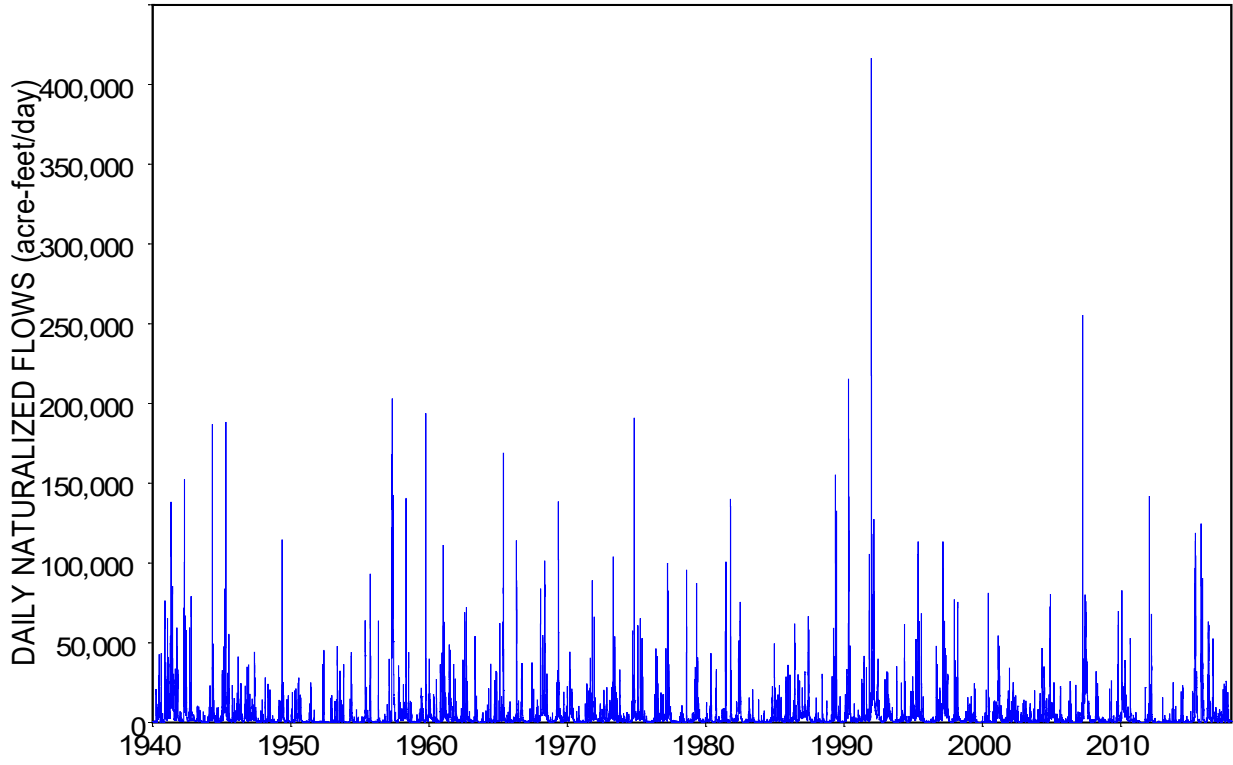


Figure 9.3 Daily Naturalized Flows at Control Point WacoG

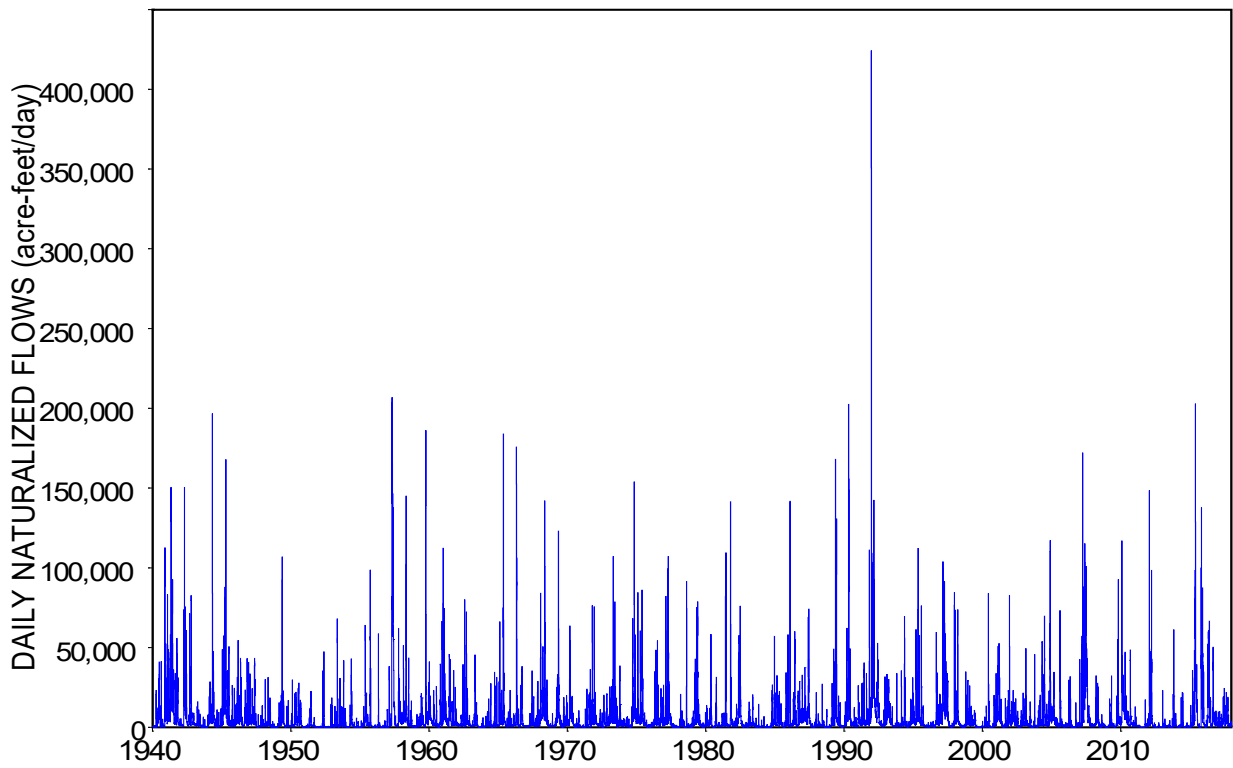


Figure 9.4 Daily Naturalized Flows at Control Point High

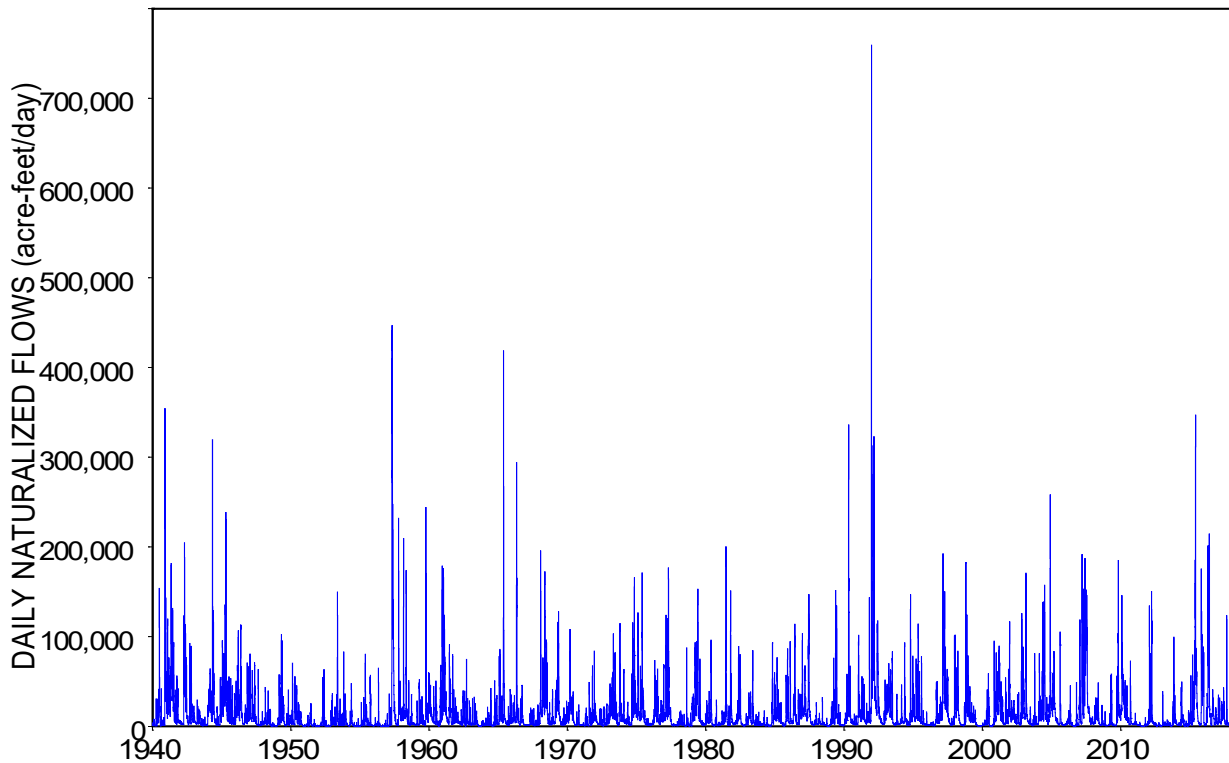


Figure 9.5 Daily Naturalized Flows at Control Point Hemp

HEC-DSSVue based procedures adopted for Example 9.2 proceed as follows resulting in the metrics tabulated in Table 9.6 and plotted in Figures 9.1 through 9.5 and Figures 9.6 and 9.7. The methodology begins with the main menu of *HEC-DSSVue*, which is illustrated by the screen-shot shown in Figure 8.1. The same naturalized flow data can be found in either the *SIMD* input file ExamplesHYD.DSS or the *SIMD* output file DailyCh7.DSS described in Chapter 7.

Working directly with the original DSS file would have been fine. However, the records were copied to a new DSS file with filename Ch9Example2.DSS using the "copy to" option accessed through "Edit" in the menu bar. The file Ch9Example2.DSS is included in the example datasets distributed with the WRAP manuals and software. The component parts of the pathnames are easily named or renamed to provide descriptive labels for the DSS records created as the computational procedure proceeds multiple steps.

The plots of the original naturalized daily flows in Figures 9.1 through 9.5 and Figures 9.6 and 9.7 were prepared using the "plot" feature accessed through "Display" in the menu bar. The plots were copied from *HEC-DSSVue* directly to a *Microsoft Word* document (this chapter) through the "Copy to Clipboard" feature found under "File" in the plot editor menu bar.

The annual minimum of the 7-day flows, computed as explained on the following pages, are plotted in Figure 9.6. The results of the frequency analysis are tabulated in Table 9.6 and plotted in Figure 9.7. Table 9.6 summarizes intermediate computations as well as the final low flow frequency relationships plotted in Figure 9.7.

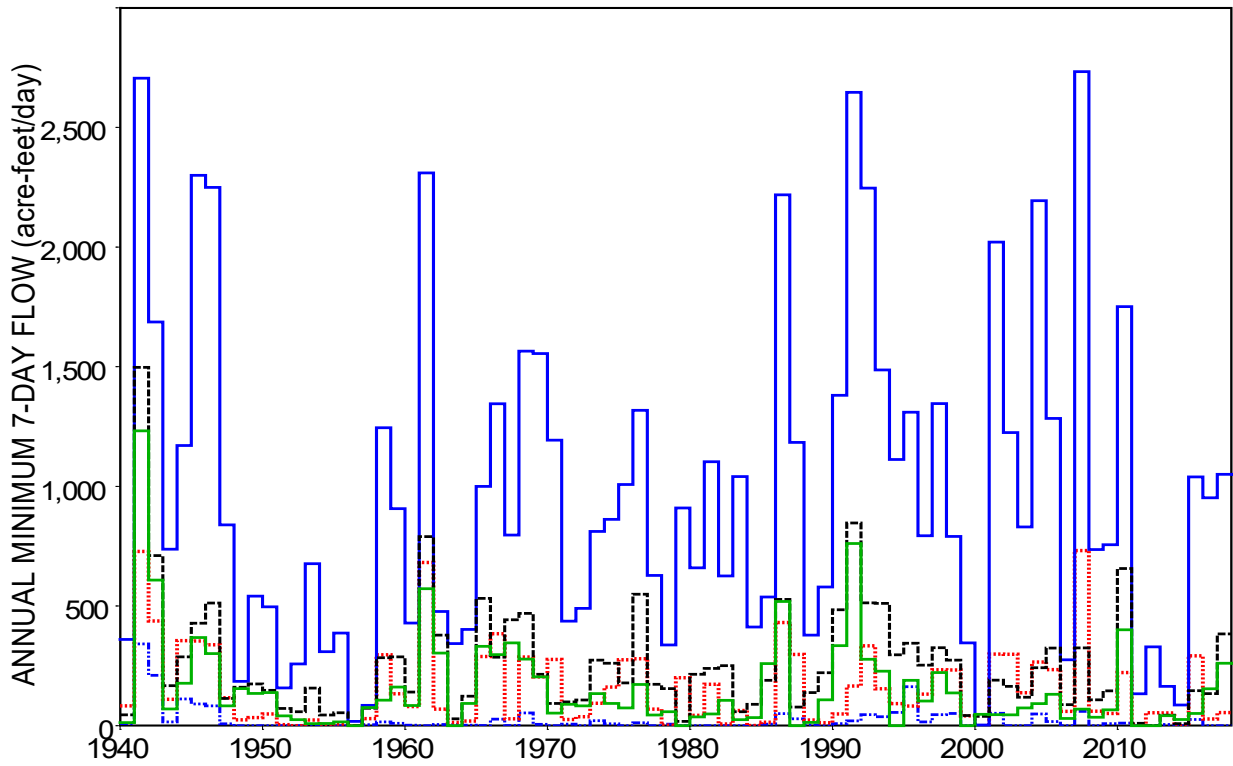


Figure 9.6 Annual Minima of 7-Day Naturalized Flows

Control Points Hemp (blue solid line), High (black dashed),
Waco (green solid), Camer (red dots), and Belton (blue dashes and dots)

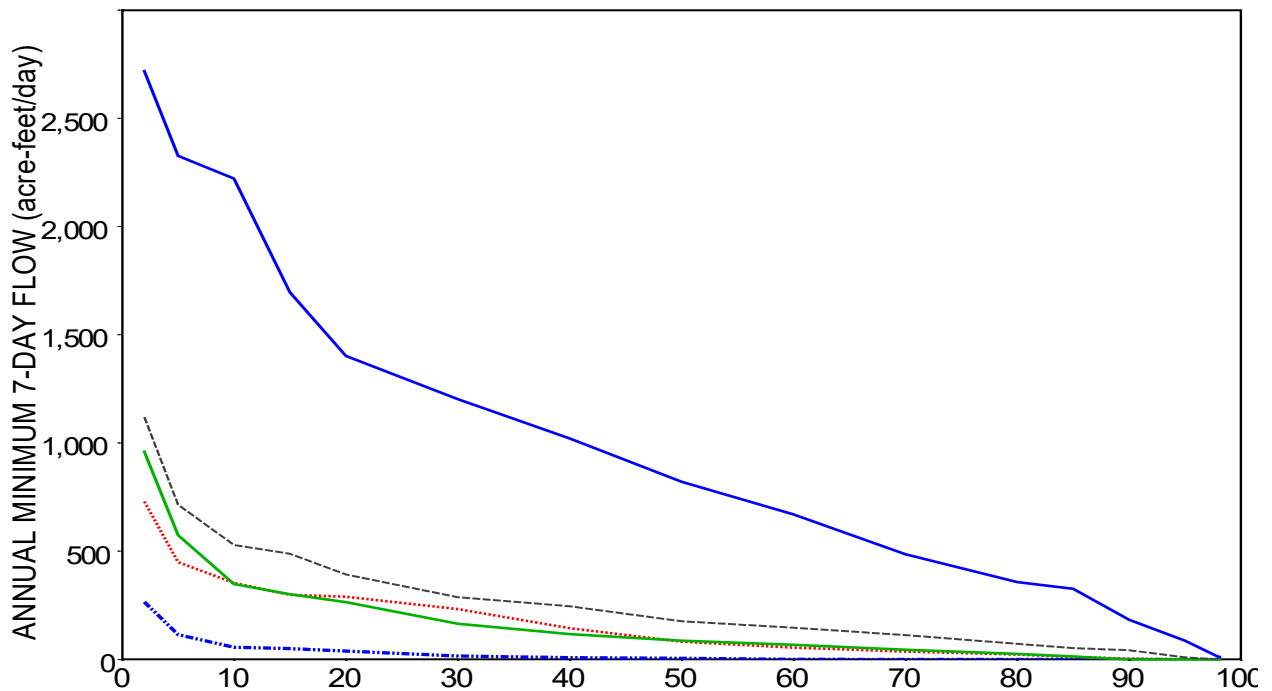


Figure 9.7 Frequency Curves for Annual Minimum 7-Day Naturalized Flow in Example 9.2

Table 9.6
Statistics for the Times Series Datasets of Example 9.2

Control Point	Belton	Camer	WacoG	High	Hemp
<u>Basic Statistics for Daily Naturalized Flows</u>					
Number of valid values	28,490	28,490	28,490	28,490	28,490
Mean (acre-feet/day)	1,369.2	3,651.3	5,095.7	6,179.3	14,634
Standard Deviation (ac-ft/day)	3,755.6	9,346.2	12,914	14,545	27,573
Skew Coefficient (ac-ft/day)	14.113	9.1634	7.8509	6.8382	5.9960
Minimum (acre-feet/day)	0.0	0.0	0.0	0.0	0.0
Maximum (acre-feet/day)	198,850	289,749	416,556	424,285	759,482
Accumulative Volume (ac-ft)	3.9009E7	1.0402E8	1.4517E8	1.7605E8	4.1693E8
<u>Basic Statistics for 7-Day Low Flows</u>					
Number of valid values	28,484	28,484	28,484	28,484	28,484
Mean (acre-feet/day)	1,369.5	3,651.6	5,096.6	6,180.5	14,636
Standard Deviation (ac-ft/day)	2,989.5	7,628.2	11,215.5	12,795	25,309
Skew Coefficient (ac-ft/day)	5.3834	6.2073	6.0035	5.6232	4.8251
Minimum (acre-feet/day)	0.0	0.0	0.0	0.0	2.1713
Maximum (acre-feet/day)	49,533	159,321	216,845	234,597	478,022
Accumulative Volume (ac-ft)	3.9007E7	1.0401E8	1.4517E8	1.7604E8	4.1689E8
<u>Basic Statistics for Annual Minima of 7-Day Low Flows</u>					
Number of valid values	78	78	78	78	78
Mean (acre-feet/day)	23.120	154.01	153.72	251.26	965.10
Standard Deviation (ac-ft/day)	51.321	167.14	196.68	238.14	687.73
Skew Coefficient (ac-ft/day)	4.1754	1.5939	2.9394	2.3873	0.9110
Minimum (acre-feet/day)	0.0	0.0	0.0	0.0	2.1713
Maximum (acre-feet/day)	341.20	731.13	1,231.8	1,497.2	2,732.8
Accumulative Volume (ac-ft)	1,803.4	12,012	11,990	19,598	75,278
<u>Annual Minima of 7-Day Flows Associated with Specified Exceedance Frequencies</u>					
$P = [m/(N+1)]100\%$					
2%	265.24	729.38	958.77	1119.87	2717.02
5%	114.20	449.26	573.97	714.46	2326.28
10%	55.85	353.58	347.84	528.08	2220.90
15%	50.14	298.30	301.07	488.19	1696.41
20%	38.74	289.41	264.01	392.03	1401.79
30%	15.49	232.72	164.50	287.06	1202.68
40%	7.86	144.16	116.87	245.62	1020.37
50%	4.69	82.10	86.39	176.23	820.89
60%	0.06	54.30	67.62	146.82	669.76
70%	0.00	36.02	44.73	111.97	485.92
80%	0.00	22.35	25.28	72.13	357.05
85%	0.00	11.21	13.03	52.50	326.32
90%	0.00	3.68	0.00	42.07	183.04
95%	0.00	0.00	0.00	9.70	86.12
98%	0.00	0.00	0.00	0.00	11.27

The metrics tabulated in the upper rows of Tables 9.6 were computed using the "basic" option accessed through the *Tools/Math Function/Statistics* menu path. The basic statistics include the number of values, number of missing values, mean, standard deviation, skew coefficient, minimum, maximum, and accumulated volume for the time series quantities. The basic statistics are presented for the three datasets created in the multiple-step computational process: (1) daily naturalized flows, (2) 7-day moving averages of the daily naturalized flows, and (3) the annual minima of the 7-day moving averages of the daily naturalized flows.

The daily naturalized flows in acre-feet/day from the WAM described in Chapters 7 and 8 are converted to 7-day moving averages. Since seven days are required for 7-day averages, the first six days of the first year (1940) are not considered in the computation of the minimum 7-day mean flow rate for 1940. Otherwise, 365 or 366 (leap year) 7-day moving averages are computed for each of the 78 years of the January 1940 through December 2017 period-of-analysis.

The *smoothing* options in *HEC-DSSVue* are *centered moving average*, *Olympic smoothing average*, and *forward moving average*. The "forward moving average" accessed through the "smoothing" menu is used to compute the 7-day moving averages for the five control points, which are recorded in the DSS file as a set of five DSS records.

The "minimum" option and "year" period are selected in the "time functions" menu to determine the minimum 7-day moving average in each of the 78 years.

The "duration analysis" feature, which is based on the Weibull formula (Eq. 9.2), is employed to assign probabilities to each of the 78 annual 7-day minimum flows at the five sites. The results tabulated in Table 9.6 reflect an option that limits the tabulation to the 23 pre-set standard probabilities shown, with the flows interpolated from the complete array. Optionally, all 78 quantities or user-selected probabilities can be included in the tabulation. The *TABLES 7FFA* record illustrated by Table 9.11 in Example 9.4 also includes a Weibull formula based option.

The "duration analysis" feature of *HEC-DSSVue* has options for displaying the Weibull formula computational results as either a table or plot. The flow-duration (flow versus exceedance frequency) curves of Figure 9.7 provide a graphical display of the quantities in Table 9.6. The terms *duration analysis* and *frequency analysis* are used interchangeably. Depending on the variable being analyzed and the application, analysis results are viewed as estimates of percent-of-time, duration, frequency, probability, chance, or likelihood.

The basic statistics in the upper portion of Table 9.6 provide insight regarding both actual stream flow characteristics and the computational methodologies. The three datasets each consist of groups five DSS records (five control points) stored in the DSS file. The 28,490 daily naturalized flows at Belton have a mean of 1,369.2 acre-feet/day and total volume of 39,009,000 acre-feet (1,369.2 acre-feet/day x 28,490 days). With January 1-6, 1940 missing, the 7-day low flow dataset has 6 fewer days but essentially the same mean and total volume as the daily flows. The variability measured by the standard deviation is reduced by the 7 day averaging. The third set of basic statistics in Table 9.6 are for the final random variable (annual 7-day low flows) to which the duration analysis (frequency analysis) was applied. The exceedance frequency relationships for the 78 annual minima of 7-day average flows graphically displayed in Figure 9.7 were plotted from the *duration analysis* component of *HEC-DSSVue*.

Example 9.3 – Flood Frequency Analysis with TABLES DATA and 6FRE Records

The random variable in the statistical analyses of Examples 9.3, 9.4, 9.5, and 9.6 is the maximum end-of-day (midnight) storage contents in acre-feet in each of the six reservoirs to occur in each year of the 1940-2017 daily *SIMD* simulation. This type of annual peak storage frequency analysis can be employed in assessments of flood control capabilities of reservoirs.

Example 9.3 employs the DATA and 6FRE records in *TABLES* in a similar manner as the earlier Example 9.1. The DATA record routine can read and manipulate any of the simulation results from the *SIM* or *SIMD* output OUT and SUB files, with the resulting data array then accessed by monthly type 2 or daily type 6 time series record routines or monthly 2FRE or daily 6FRE record frequency analysis routines. Example 9.4 illustrates an alternative to the Example 9.3 approach using the *TABLES* 7FFA record with a *SIMD* AFF output file, which is designed specifically for flood frequency analyses.

Storage capacities and operating rules for the six reservoirs are described in Tables 7.3, 7.7, and 7.8 of Chapter 7. End-of-day storage volumes for each of the 28,490 days of the final *SIMD* simulation presented in Chapters 7 and 8 are plotted below in Figure 9.8.

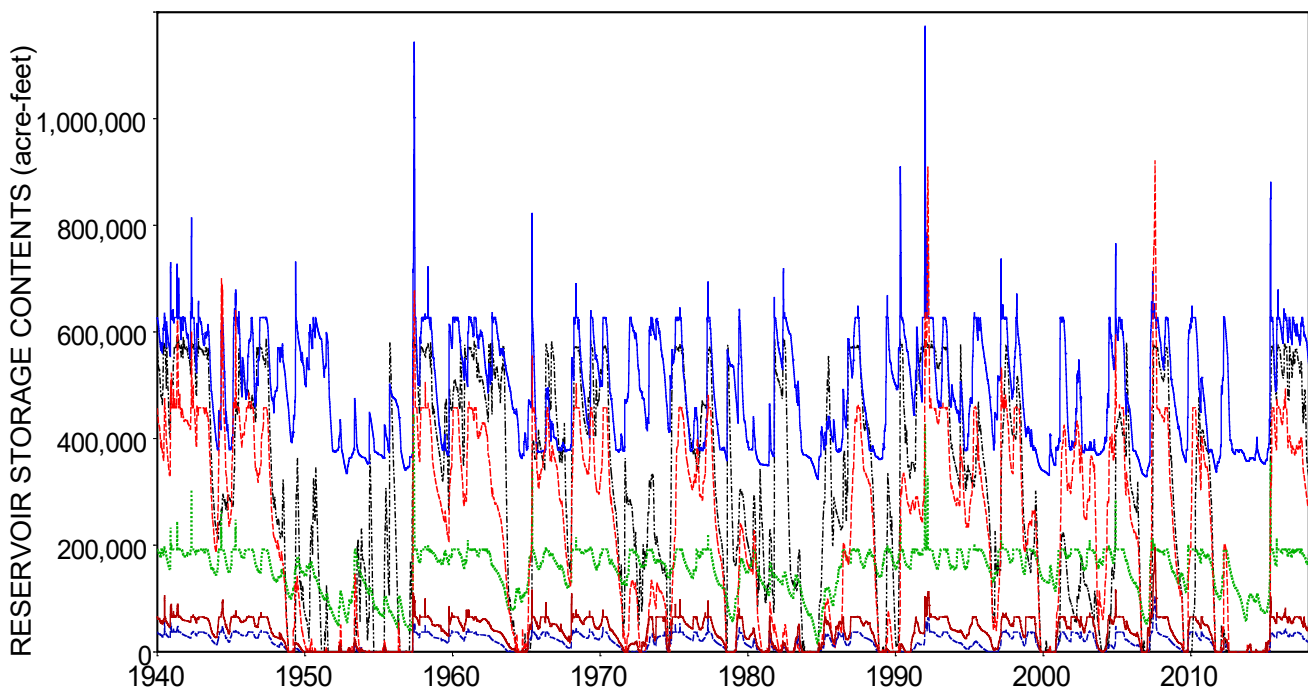


Figure 9.8 Storage Contents of Whitney (blue solid line), Belton (red dashes), Waco (green dots), Possum Kingdom (black dots and dashes), Granger (red solid), and Georgetown (blue dashes) Reservoirs

The *TABLES* input records in Table 9.7 produce the TOU file reproduced as Table 9.8. The DATA record creates a data array containing the maximum end-of-day storage contents in each of the 78 years of the 1940-2017 simulation for each of the six reservoirs. Option 4 selected

in DATA record field 13 tabulates the array of 78 peak storage volumes for each of the six reservoirs along with their dates of occurrence in the TOU file. Frequency analysis specifications include selection of the relative frequency option by the first 6FRE record and the log-normal probability distribution option by the second 6FRE record.

Table 9.7
TABLES Input TIN File Records for Frequency Analyses
of Maximum Annual Reservoir Storage Contents

DATA6STO	0	6	1	0	0	3			4
IDEN		PK	Whit	WacoL	Belton	George	Grang		
6FRE	15	0	-6	3	1				
6FRE	15	0	-6	3	2				

Table 9.8
TABLES Output TOU File for Example 9.3
Peak Annual Storage Tabulation, Relative Frequency Table, Log-Normal Frequency Table

DATA RECORD	VARIABLE	6STO	ANNUAL	SERIES	DATASET					
YEAR	PK	Whit	WacoL	Belton	George	Grang				
1940	581881.38	8/20	730831.31 11/30	233099.55 11/30	522278.78 12/23	57221.41 7/ 5	106444.90 7/ 5			
1941	590983.00	10/ 6	726889.19 5/ 9	244761.25 5/12	621628.56 5/20	47492.61 6/ 5	89548.27 6/ 2			
1942	587821.19	4/26	813811.62 5/ 1	304537.06 4/30	600729.25 5/ 1	38087.72 6/14	69351.90 6/14			
1943	571003.94	6/10	615461.31 1/ 1	192100.00 1/ 1	457600.00 1/ 1	37100.00 1/ 1	65500.00 1/ 1			
1944	295437.59	6/17	627100.00 5/27	263934.59 5/ 7	700811.31 5/12	47329.37 6/ 9	97089.21 6/ 9			
1945	570737.94	7/22	679172.06 4/27	248158.45 4/27	639492.12 4/28	41953.61 4/30	76731.34 4/30			
1946	577698.44	12/13	627100.00 5/19	192100.00 1/ 9	488422.75 3/17	37842.20 3/17	67370.34 3/20			
1947	587784.94	5/22	627100.00 1/ 1	192100.00 2/22	457600.00 3/21	41183.21 1/21	74775.44 1/20			
1948	322044.81	7/14	578221.44 6/29	155630.27 6/ 3	209918.61 3/ 1	17636.30 5/14	36501.41 4/13			
1949	364553.94	6/30	732012.00 5/19	178835.22 6/29	142325.53 6/27	6761.73 5/11	17533.41 4/28			
1950	346220.31	9/30	627100.00 7/30	168050.36 6/13	23817.57 6/13	502.51 2/14	1857.03 6/ 6			
1951	124689.62	6/23	599168.31 6/17	118551.84 1/ 1	8877.62 6/17	19.69 3/28	239.99 5/26			
1952	2840.46	5/24	436263.72 5/28	113769.23 5/28	50246.36 6/ 7	6287.03 6/ 1	14863.09 5/28			
1953	230606.27	10/31	475856.78 5/17	192100.00 5/16	145621.05 5/29	12269.49 5/29	23253.44 5/26			
1954	370702.19	5/31	448971.41 5/20	132808.92 1/ 1	2393.32 5/12	1461.30 1/ 1	1530.22 1/20			
1955	578987.69	10/ 5	502695.00 9/30	104042.98 5/29	22214.89 5/26	4594.59 5/20	10621.79 5/18			
1956	361260.84	1/ 1	476233.81 1/ 1	104042.98 5/10	55644.94 5/ 8	1163.52 5/ 2	1256.05 11/ 4			
1957	591146.00	5/22	1144066.38 5/31	446390.91 5/ 9	677450.88 6/ 6	51673.07 6/14	109371.57 5/ 8			
1958	582152.94	7/10	723001.25 5/ 8	201715.25 5/ 8	506316.38 2/28	49993.17 2/27	100335.01 2/27			
1959	493579.00	10/23	615041.50 10/18	192100.00 12/25	405280.75 12/31	41993.46 10/11	84900.50 10/ 4			
1960	575939.12	10/31	627100.00 1/10	192100.00 1/ 4	457600.00 1/20	39172.77 12/14	72888.71 12/13			
1961	583174.62	6/22	629313.88 2/10	209924.39 1/16	468427.62 2/15	43051.30 2/13	79214.77 1/17			
1962	585345.31	9/13	637247.06 9/14	192100.00 1/ 1	429622.78 2/ 2	31901.75 1/ 4	62122.89 2/21			
1963	573338.81	6/ 9	609411.69 1/ 1	151035.55 1/ 9	274851.94 1/ 9	17937.82 1/ 1	38802.50 1/ 1			
1964	62341.79	1/ 1	472514.91 1/ 1	118610.22 6/28	50335.00 1/ 1	1244.05 9/27	6947.01 3/24			
1965	416685.03	10/30	823293.69 5/25	340210.53 5/28	554570.25 5/28	57212.43 5/26	116940.65 5/25			
1966	581029.19	9/22	495810.03 6/25	194117.06 4/30	457600.00 5/27	38112.60 5/ 5	92678.52 5/ 5			
1967	463901.72	1/ 1	400281.00 1/ 6	167826.78 1/ 1	353723.88 1/ 1	24143.81 1/ 1	52821.71 5/ 2			
1968	572127.00	6/12	691480.56 5/17	215153.34 5/18	503962.34 5/22	46413.03 5/20	109078.61 1/29			
1969	583156.31	5/13	640937.31 5/16	195421.39 5/ 8	457600.00 5/11	43679.10 4/15	77228.55 4/15			
1970	573854.12	5/ 4	627100.00 4/ 1	192100.00 2/20	458492.06 5/30	45645.07 3/11	78520.98 3/13			
1971	363420.00	9/15	608712.50 12/31	178851.48 12/17	225033.91 1/ 1	16034.05 1/ 1	32314.85 1/ 1			
1972	286757.56	1/ 1	627100.00 1/ 4	192100.00 1/ 6	133905.70 3/10	1564.85 1/11	20836.80 6/19			
1973	335322.56	7/20	627100.00 6/ 7	192100.00 3/16	133993.94 6/26	33780.38 7/22	65969.87 10/17			
1974	551101.81	12/31	602043.88 1/ 8	170793.09 2/ 4	178571.06 12/31	41403.08 11/ 4	65500.00 1/ 1			
1975	575988.31	5/31	645955.50 5/29	193019.69 5/29	458695.88 5/31	54020.86 5/28	99077.30 5/31			
1976	470333.47	11/30	459187.94 7/ 6	192100.00 7/14	399612.78 8/ 1	37100.00 5/17	66991.41 4/30			
1977	571228.31	6/ 6	693973.75 4/24	217151.06 4/25	480855.69 4/30	68263.64 4/24	95900.81 4/25			
1978	575326.31	8/25	566941.38 8/13	129152.46 1/ 1	195529.75 1/ 1	15307.28 1/ 1	27749.03 2/27			
1979	304340.31	7/ 4	643314.56 6/ 8	174059.91 7/26	240121.89 7/ 1	45017.81 6/ 7	81385.99 6/ 7			
1980	343670.06	10/31	440895.12 5/20	192100.00 6/ 7	227082.95 6/10	25341.51 5/31	44985.52 5/19			
1981	586494.31	10/29	665795.31 10/20	166715.25 6/30	94159.30 6/30	37100.00 6/28	65500.00 6/28			

1982	586485.69	5/29	719515.88	6/ 2	148815.98	6/30	50910.22	7/13	9611.67	5/22	19121.98	5/20
1983	192631.84	6/30	566885.69	1/ 1	144563.77	4/14	24789.04	4/ 8	29430.23	6/20	51786.06	6/19
1984	155930.27	12/31	422789.44	12/31	77594.38	1/ 1	16518.11	10/22	5737.66	12/28	16010.12	10/31
1985	555133.44	6/20	442442.09	6/15	128419.55	12/31	99619.37	5/30	33359.05	4/16	65500.00	3/27
1986	573122.00	10/20	587413.88	10/16	192100.00	6/ 2	262100.94	12/31	37100.00	2/21	65500.00	6/16
1987	575427.94	5/29	648189.38	6/17	192100.00	1/13	463504.56	6/28	37654.53	6/ 7	67477.56	6/ 7
1988	435562.25	1/11	446012.16	1/ 1	191760.70	4/ 3	333400.03	1/ 1	25943.73	1/ 1	58107.39	1/ 9
1989	336289.09	6/27	667830.12	6/15	199856.62	6/18	75715.61	7/ 5	3111.84	5/27	6886.02	5/24
1990	587180.00	4/30	910280.12	4/30	247986.34	5/ 3	334703.47	7/23	1030.73	5/18	14718.92	5/20
1991	585557.31	12/29	1143993.75	12/31	411427.94	12/31	616809.75	12/31	52425.41	12/31	104608.65	12/30
1992	582272.00	6/11	1173137.88	1/ 5	428522.31	1/ 4	910361.38	3/12	63947.13	3/31	112738.58	3/31
1993	572411.44	2/28	627100.00	3/28	192100.00	1/26	467370.91	3/22	38347.90	6/28	67818.38	6/28
1994	576674.88	5/31	507267.59	5/31	192100.00	3/15	386407.97	5/26	20108.11	1/ 1	40973.18	5/21
1995	470103.59	8/17	636076.69	5/ 9	203193.80	5/ 9	461431.84	6/ 2	20050.67	6/16	66019.17	4/ 8
1996	355314.66	1/ 1	555473.56	1/ 1	192100.00	12/25	287092.91	1/ 1	5393.43	12/31	38627.96	1/ 3
1997	576101.56	6/29	736942.69	2/28	222381.84	2/25	533957.19	3/ 5	40367.53	7/ 1	73411.53	4/ 9
1998	517248.78	3/31	671987.50	3/21	192100.00	1/ 1	460851.31	2/27	37619.66	3/21	65862.40	3/21
1999	302215.19	6/30	422673.81	1/ 1	192100.00	1/ 1	266209.97	4/19	37100.00	1/ 1	65500.00	1/ 1
2000	37796.95	11/20	409227.91	6/25	162272.17	6/26	80315.64	12/31	10752.27	12/31	46759.04	12/31
2001	222747.16	5/13	627100.00	2/28	192100.00	1/19	425746.81	6/ 1	37719.71	5/ 8	67605.30	5/ 8
2002	180173.94	7/31	548305.50	6/ 2	192100.00	1/ 1	432485.84	4/24	37100.00	1/ 1	65500.00	1/ 1
2003	120239.41	1/ 2	398955.12	6/20	209776.55	2/26	367021.34	4/ 2	40549.75	2/26	73381.48	2/26
2004	423539.50	12/28	766447.12	11/30	281895.25	11/29	595285.25	11/30	47594.84	11/30	117033.09	11/28
2005	578729.56	8/28	627100.00	2/16	192100.00	1/ 1	463147.81	3/ 3	37304.30	3/ 3	66320.53	3/ 3
2006	319088.03	5/30	410702.53	1/ 1	136611.30	1/ 1	240766.33	1/ 1	15125.01	1/ 1	36639.20	5/19
2007	576383.12	6/30	713909.62	6/ 3	214361.41	5/ 7	922041.50	7/31	105599.04	7/31	196523.62	7/31
2008	571596.75	4/30	627100.00	4/18	192100.00	3/24	457723.62	5/16	31883.15	1/ 1	65772.13	5/16
2009	209412.52	1/ 1	614645.94	12/20	201724.64	10/31	190049.66	12/31	37100.00	12/17	65500.00	12/10
2010	477972.12	7/23	648241.69	1/31	192100.00	1/ 1	457600.00	2/19	37171.04	1/31	65504.66	1/30
2011	387979.59	1/ 1	445195.97	1/ 1	183093.56	2/10	348438.84	1/30	26961.65	1/ 1	51354.42	1/27
2012	48174.60	1/30	629764.50	3/25	192100.00	3/26	203066.69	4/18	16439.73	3/31	25219.08	3/30
2013	349.77	1/14	379066.91	5/22	120275.70	1/ 1	12175.43	10/31	0.00	1/ 1	13406.73	12/31
2014	2537.45	7/ 9	402453.22	6/27	110544.02	6/29	9569.72	1/ 1	58.12	5/31	14301.62	1/ 4
2015	576542.44	11/30	881689.06	5/31	358871.66	5/31	475611.72	11/ 2	38465.81	11/10	104095.44	5/31
2016	579921.62	5/14	644117.62	4/24	195116.34	5/27	493622.88	5/27	43405.89	5/27	81801.36	5/31
2017	568169.56	2/28	627100.00	7/13	192100.00	2/21	402545.19	6/16	36796.10	3/10	65500.00	1/18

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS
Daily Data from January 1940 through December 2017

Res	PK	Whit	WacoL	Belton	George	Grang	TOTAL
Mean	294629.72	489737.66	155600.84	225389.70	18144.42	36073.41	1219578.00
Std Dev	204109.88	102748.59	41352.73	178979.44	15244.62	27321.09	503987.69
Minimum	0.00	323067.31	13741.59	0.00	0.00	0.00	336808.91
99%	0.00	335973.31	47184.47	0.00	0.00	0.00	394807.53
98%	0.00	342845.91	56004.81	0.00	0.00	0.00	421604.72
95%	0.00	354694.25	71235.19	0.00	0.00	0.00	451770.84
90%	0.00	365963.69	92968.77	0.00	0.00	0.00	490924.50
80%	55327.98	378701.25	120599.85	4654.95	0.00	776.13	681177.31
70%	148497.70	399146.53	141920.47	54488.88	2762.11	12390.31	874961.62
60%	225298.48	444085.19	156772.09	154697.61	11312.10	28116.67	1071942.12
50%	303762.19	485182.25	167320.95	245777.91	18551.64	40247.85	1222489.88
40%	382989.12	528369.94	178369.84	304837.16	25518.03	50573.16	1388293.38
30%	458783.00	568814.25	186728.95	357851.75	30059.55	58442.50	1575013.00
20%	522407.66	600938.44	191818.05	415498.47	34611.98	65238.87	1750797.38
10%	567447.75	625841.94	192100.00	457600.00	37100.00	65500.00	1891318.25
Maximum	591146.00	1173137.88	446390.91	922041.50	105599.04	196523.62	2970679.50

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS
Daily Data from January 1940 through December 2017

Res	PK	Whit	WacoL	Belton	George	Grang	TOTAL
Mean	294629.72	489737.66	155600.84	225389.70	18144.42	36073.41	1219578.00
Std Dev	204109.88	102748.59	41352.73	178979.44	15244.62	27321.09	503987.69
Minimum	0.00	323067.31	13741.59	0.00	0.00	0.00	336808.91
99%	0.03	293861.38	67487.47	0.00	0.00	0.00	359699.38
98%	0.16	311184.62	74014.05	0.02	0.00	0.01	410031.56
95%	1.70	339102.97	85006.27	0.25	0.03	0.14	499037.84
90%	14.29	366003.41	96135.32	2.54	0.24	1.16	594206.94

80%	187.91	401449.59	111579.53	43.05	3.56	15.13	734057.88
70%	1204.20	429119.62	124233.23	330.91	24.64	96.59	854905.56
60%	5888.90	454268.75	136176.11	1890.23	128.81	470.93	973804.94
50%	25963.02	479106.25	148375.08	9635.97	604.33	2070.41	1099849.38
40%	114465.93	505301.75	161666.88	49122.00	2835.31	9102.39	1242208.25
30%	559773.75	534915.69	177208.33	280593.25	14819.39	44379.61	1414973.38
20%	3587303.25	571784.88	197304.69	2156700.50	102660.20	283405.22	1647920.00
10%	47165664.00	627160.25	229001.83	36487996.00	1503690.12	3708022.25	2035769.88
Maximum	591146.00	1173137.88	446390.91	922041.50	105599.04	196523.62	2970679.50

Option 3 for the input parameter TABLE in field 5 of the 6FRE record in Table 9.7 produces the abbreviated frequency table in the format shown above with 12 exceedance percentages. Option 2 lengthens the table to include 21 rather than 12 exceedance percentages. The default option 1 has a row format instead of column format.

The two frequency tables share the same mean and standard deviation computed with Equations 9.5 and 9.6 and the minimum and maximum taken from the list of 78 annual peak storage volumes tabulated in the first table in Table 9.8. However, the storage volumes associated with the twelve exceedance frequencies computed based on relative frequency (Eq. 9.1) in the first frequency table of Table 9.8 versus the log-normal probability distribution (Eq. 9.4) in the second frequency table of Table 9.8 are very different.

The DATA and 6FRE records provide flexible options illustrated by Examples 9.1 and 9.3 which are generally applicable to analyses of any of the variables in the *SIM* and *SIMD* time series input and simulation results. The AFF file and 7FFA record employed in Example 9.4 are designed specifically for annual flood frequency analyses of stream flow and reservoir storage.

Example 9.4 – Flood Frequency Analysis with AFF File and 7FFA Record

The *TABLES* flood frequency analysis 7FFA record routine reads annual series of maximum daily naturalized and regulated flow volumes, maximum end-of-day storage volume, and excess flow (defined later) for each year of the period-of-analysis from a *SIMD* output AFF file which is activated by the input parameter AFF in field 6 of the *JT* record. The 7FFA record input parameters control a frequency analysis based on the log-Pearson type III probability distribution (Eq. 9.4). With a zero skew coefficient entered on the 7FFA record, the log-Pearson distribution becomes the log-normal distribution. An optional table with Weibull (Eq. 9.2) exceedance frequencies can also be created. The methodology is explained in *Reference Manual* Chapter 7 and *Users Manual* Chapter 5. *TABLES* also has related capabilities, not applied in this example, to develop expected annual economic flood damage tables along with the frequency analysis tables, which are also described in the *Reference* and *Users Manuals*.

The default *SIMD JT* record AFF option 1 is to not create an AFF file. Option 2 creates an AFF table that contains the control points listed on one or more *CO* records. The first three years of the 78 year annual flood frequency AFF file for Example 9.4 is reproduced as Table 9.9 to illustrate its format. AFF files automatically include columns for each of four random variables consisting of peak annual values of (1) naturalized flow, (2) regulated flow, (3) storage volume, and (4) excess flow adjustments. Creation of the AFF file of Table 9.9 is controlled by the following two records in the *SIMD* input DAT file. The AFF file includes the six control points listed on the *CO* record, which are reservoir locations.

JT 0 0 0 0 2
CO PK Whit WacoL Belton George Grang

Table 9.9
Beginning of SIMD Output AFF File for Example 9.4

WRAP-SIMD (April 2019) Flood Frequency Analysis File
78 6

YEAR	CPID	NAT-FLOW	REG-FLOW	STORAGE	EXCESS FLOW
1940	PK	61268.6	36927.9	581881.4	220195.
1940	Whit	79658.9	52877.7	730831.3	0.
1940	WacoL	21175.2	39188.2	233099.5	0.
1940	Belton	40667.6	19411.6	522278.8	0.
1940	George	11991.6	7933.9	57221.4	0.
1940	Grang	38584.6	19834.7	106444.9	0.
1941	PK	87320.2	106956.9	590983.0	2163712.
1941	Whit	91443.4	89486.7	726889.2	0.
1941	WacoL	11456.3	39669.4	244761.2	0.
1941	Belton	26582.2	19834.7	621628.6	0.
1941	George	6735.2	7248.0	47492.6	0.
1941	Grang	21671.9	19834.7	89548.3	0.
1942	PK	62894.8	58522.0	587821.2	626938.
1942	Whit	114970.3	53621.1	813811.6	0.
1942	WacoL	52065.1	39669.4	304537.1	0.
1942	Belton	49998.6	19834.7	600729.2	0.
1942	George	6634.9	6533.5	38087.7	0.
1942	Grang	21349.6	19834.7	69351.9	0.
1943	PK	7622.3	3642.4	571003.9	17166.
1943	Whit	10277.9	3420.2	615461.3	0.
1943	WacoL	2707.4	2476.6	192100.0	0.
1943	Belton	3504.4	3882.2	457600.0	0.
1943	George	611.2	1195.5	37100.0	0.
1943	Grang	1967.2	2979.7	65500.0	0.
1944	PK	13636.8	0.0	295437.6	0.
1944	Whit	81407.1	15274.1	627100.0	0.
1944	WacoL	37980.3	39669.4	263934.6	0.
1944	Belton	69840.2	19834.7	700811.3	0.
1944	George	5671.1	7933.9	47329.4	0.
1944	Grang	18248.3	22203.8	97089.2	0.
1945	PK	34153.9	3642.4	570737.9	1779.
1945	Whit	64020.6	49586.8	679172.1	0.
1945	WacoL	69621.2	39669.4	248158.5	0.
1945	Belton	89295.6	19834.7	639492.1	0.
1945	George	4684.8	3508.8	41953.6	0.
1945	Grang	15074.4	14456.4	76731.3	0.
1946	PK	37412.6	18654.7	577698.4	108407.
1946	Whit	46778.8	27127.0	627100.0	0.
1946	WacoL	14665.0	14475.9	192100.0	0.
1946	Belton	26018.6	19834.7	488422.8	0.

A 7FFA record creates an annual frequency table based on the log-Pearson type III probability distribution or log-normal distribution for a selected variable from the *SIMD* AFF file and any of three other optional tables. The tables are created in the TOU file. The 7FFA tables are listed as follows. The first three tables are included in this example, but the fourth is not.

1. Log-Pearson type III, or with zero skew coefficient log-normal, annual frequency table.
2. Statistics table showing the statistics computed in the frequency table.
3. Table of ranked annual peaks with Weibull probabilities.
4. Economic flood damage table with expected value of flood damage.

The 7FFA frequency tables tabulate the values of the random variable which have the probability of being equaled or exceeded in any year as expressed by the exceedance frequency and recurrence intervals in the table heading. The recurrence interval or return period (T) in years is the reciprocal of the annual exceedance probability (P).

$$T = \frac{1}{P} \quad \text{or} \quad P = \frac{1}{T} \quad (9.8)$$

The third 7FFA record table is a tabulation of the selected time annual series of maximum daily values each year for naturalized flows, regulated flows, or reservoir storage with exceedance probabilities assigned by the Weibull formula.

$$P = \frac{m}{N+1} \quad (9.9)$$

where P denotes annual exceedance probability, m is the rank of the values (m = 1, 2, 3, ... , 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. Whereas the DATA record table illustrated by Table 9.4 lists the annual series in chronological order, the 7FFA record tabulates the data in order of magnitude (rank) as illustrated in Table 9.11.

The TABLES input TIN file records shown in Table 9.10 create the TABLES output TOU file replicated as Table 9.11. One of the four previously noted random variables is selected in 7FFA record field 2. The TABLES output TOU file of Table 9.11 presents the results of performing the set of frequency analyses for annual maximum end-of-day storage volumes of the six reservoirs located at the six listed control points. The same analyses could be performed for the summation of storage and excess flow for the reservoirs and for naturalized and/or regulated flows at any or all of the control points. A 7FFA record is entered for each variable of interest.

Table 9.10
Records in TABLES Input TIN File of Example 9.4

7FFA	4	2	0	6	6		
IDEN		PK	Whit	WacoL	Belton	George	Grang
7FFA	4	2	1	6			
IDEN		PK	Whit	WacoL	Belton	George	Grang

The Example 9.4 TIN file contains two 7FFA records repeating the frequency analysis with two different values for the skew coefficient (G, Eq. 9.7). Option 6 is selected for SKEW in 7FFA field 6 of the first 7FFA record setting G equal to zero. The default option 1 (blank field 6) is activated by the second 7FFA record which means that G is computed with Equation 9.7. With a zero skew coefficient, the log-Pearson III distribution is identical to the log-normal distribution. The first frequency table in Table 9.11 has the same values as the second frequency table in Table 9.7 for the metrics that shared by the two different tables since both employ the log-normal probability distribution. The 6FRE and 7FFA tables have different formats.

The frequency factor z=K for the log-Pearson III distribution is determined within TABLES as a function of P and $G_{\log X}$ by linear interpolation of a built-in probability table. An abbreviated log-Pearson III probability table is provided as Table 7.18 of the *Reference Manual*.

The frequency table created by the 7FFA record also includes the expected value of the random variable. The expected value reflects the statistical concept of a probability-weighted average. The TOU file reproduced here as Table 9.11 consists of the following five tables.

1. Flood frequency analysis results table based on the log-normal distribution.
2. Statistics computed for the original data and the logarithms of the data.
3. Flood frequency analysis results table based on the log-Pearson type III distribution.
4. Statistics computed for the original data and the logarithms of the data.
5. Tabulation of data in ranked order along with Weibull (Eq. 9.2) probabilities.

Table 9.11
TABLES Output TOU File of Example 9.4

FLOOD FREQUENCIES FOR SUMMATION OF RESERVOIR STORAGE AND EXCESS FLOW

CONTROL POINT	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)									EXPECTED VALUE
	1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	
PK	15197.	394268.	1280435.	2370075.	4570058.	6984454.	10228880.	14503436.	22143064.	1105028.
Whit	344776.	601828.	736206.	817996.	915252.	984143.	1050529.	1115202.	1198934.	604505.
WacoL	92616.	188421.	243622.	278642.	321549.	352719.	383329.	413666.	453664.	192866.
Belton	13273.	224559.	624773.	1066629.	1886808.	2727402.	3799156.	5145377.	7431094.	493771.
George	211.	16664.	80940.	184903.	446221.	788333.	1315308.	2101310.	3707273.	98535.
Grang	3075.	43178.	112292.	185065.	315287.	444811.	606210.	804762.	1134428.	86108.

STATISTICS FOR SUMMATION OF PEAK ANNUAL RESERVOIR STORAGE AND EXCESS FLOW

CONTROL POINT	Statistics for Logarithms of Annual Peaks					MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	MEAN					
PK	631310.	550421.	350.	3003533.	5.5958	0.6078	0.0000	-2.8600	0.0000	
Whit	619599.	157895.	379067.	1173138.	5.7795	0.1040	0.0000	0.3234	0.0000	
WacoL	197616.	66379.	77594.	446391.	5.2751	0.1326	0.0000	0.2407	0.0000	
Belton	341051.	215102.	2393.	922042.	5.3513	0.5280	0.0000	-1.6798	0.0000	
George	30825.	19619.	0.	105599.	4.2218	0.8155	0.0000	-3.0176	0.0000	
Grang	60664.	35261.	240.	196524.	4.6353	0.4932	0.0000	-2.3578	0.0000	

FLOOD FREQUENCIES FOR SUMMATION OF RESERVOIR STORAGE AND EXCESS FLOW

CONTROL POINT	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)									EXPECTED VALUE
	1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	
PK	1467.	677777.	988767.	1034930.	1047774.	1049596.	1050048.	1050165.	1050200.	622043.
Whit	365166.	594128.	732713.	823728.	938702.	1024673.	1111139.	1198849.	1317588.	609072.
WacoL	97797.	186133.	242580.	280578.	329464.	366590.	404369.	443102.	496138.	194153.
Belton	3459.	309962.	601072.	734361.	838537.	883983.	912348.	930033.	943651.	362930.
George	8.	35017.	54981.	57574.	58185.	58255.	58271.	58274.	58275.	33511.
Grang	590.	63979.	98991.	107739.	111688.	112657.	113035.	113183.	113251.	61691.

STATISTICS FOR SUMMATION OF PEAK ANNUAL RESERVOIR STORAGE AND EXCESS FLOW

CONTROL POINT	Statistics for Logarithms of Annual Peaks					MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	MEAN					
PK	631310.	550421.	350.	3003533.	5.5958	0.6078	0.0000	-2.8600	-2.8600	
Whit	619599.	157895.	379067.	1173138.	5.7795	0.1040	0.0000	0.3234	0.3234	

WacoL	197616.	66379.	77594.	446391.	5.2751	0.1326	0.0000	0.2407	0.2407
Belton	341051.	215102.	2393.	922042.	5.3513	0.5280	0.0000	-1.6798	-1.6798
George	30825.	19619.	0.	105599.	4.2218	0.8155	0.0000	-3.0176	-3.0000
Grang	60664.	35261.	240.	196524.	4.6353	0.4932	0.0000	-2.3578	-2.3578

SUMMATION OF PEAK ANNUAL RESERVOIR STORAGE AND EXCESS FLOW

RANK	P (%)	PK	Whit	WacoL	Belton	George	Grang
1	1.27	3003533.0	1173137.9	446390.9	922041.5	105599.0	196523.6
2	2.53	2754695.0	1144066.4	428522.3	910361.4	68263.6	117033.1
3	3.80	2537615.0	1143993.8	411427.9	700811.3	63947.1	116940.6
4	5.06	1802993.8	910280.1	358871.7	677450.9	57221.4	112738.6
5	6.33	1398253.9	881689.1	340210.5	639492.1	57212.4	109371.6
6	7.59	1384625.0	823293.7	304537.1	621628.6	54020.9	109078.6
7	8.86	1214759.2	813811.6	281895.2	616809.8	52425.4	106444.9
8	10.13	1020142.6	766447.1	263934.6	600729.2	51673.1	104608.6
9	11.39	1008219.9	736942.7	248158.5	595285.2	49993.2	104095.4
10	12.66	1001536.3	732012.0	247986.3	554570.2	47594.8	100335.0
11	13.92	987995.3	730831.3	244761.2	533957.2	47492.6	99077.3
12	15.19	985919.1	726889.2	233099.5	522278.8	47329.4	97089.2
13	16.46	965259.6	723001.2	222381.8	506316.4	46413.0	95900.8
14	17.72	905757.2	719515.9	217151.1	503962.3	45645.1	92678.5
15	18.99	876193.3	713909.6	215153.3	493622.9	45017.8	89548.3
16	20.25	826178.3	693973.8	214361.4	488422.8	43679.1	84900.5
17	21.52	818459.9	691480.6	209924.4	480855.7	43405.9	81801.4
18	22.78	810722.7	679172.1	209776.5	475611.7	43051.3	81386.0
19	24.05	803910.0	671987.5	203193.8	468427.6	41993.5	79288.7
20	25.32	802076.4	667830.1	201724.6	467370.9	41953.6	79214.8
21	26.58	768692.4	665795.3	201715.2	463504.6	41403.1	78521.0
22	27.85	740893.3	648241.7	199856.6	463147.8	41183.2	77228.5
23	29.11	733840.1	648189.4	195421.4	461431.8	40549.8	76731.3
24	30.38	723728.0	645955.5	195116.3	460851.3	40367.5	74775.4
25	31.65	690916.6	644117.6	194117.1	458695.9	39172.8	73411.5
26	32.91	686105.4	643314.6	193019.7	458492.1	38465.8	73381.5
27	34.18	674022.3	640937.3	192100.0	457723.6	38347.9	69351.9
28	35.44	650373.6	637247.1	192100.0	457600.0	38112.6	67818.4
29	36.71	640543.8	636076.7	192100.0	457600.0	38087.7	67605.3
30	37.97	634449.4	629764.5	192100.0	457600.0	37842.2	67477.6
31	39.24	608025.1	629313.9	192100.0	457600.0	37719.7	67370.3
32	40.51	604471.3	627100.0	192100.0	457600.0	37654.5	66991.4
33	41.77	598873.9	627100.0	192100.0	457600.0	37619.7	66320.5
34	43.04	589331.8	627100.0	192100.0	432485.8	37304.3	66019.2
35	44.30	588169.9	627100.0	192100.0	429622.8	37171.0	65969.9
36	45.57	572516.9	627100.0	192100.0	425746.8	37100.0	65862.4
37	46.84	568169.6	627100.0	192100.0	405280.8	37100.0	65772.1
38	48.10	555133.4	627100.0	192100.0	402545.2	37100.0	65504.7
39	49.37	551101.8	627100.0	192100.0	399612.8	37100.0	65500.0
40	50.63	517248.8	627100.0	192100.0	386408.0	37100.0	65500.0
41	51.90	493579.0	627100.0	192100.0	367021.3	37100.0	65500.0
42	53.16	477972.1	627100.0	192100.0	353723.9	37100.0	65500.0
43	54.43	470333.5	627100.0	192100.0	348438.8	36796.1	65500.0
44	55.70	470103.6	627100.0	192100.0	334703.5	33780.4	65500.0
45	56.96	463901.7	615461.3	192100.0	333400.0	33359.1	65500.0
46	58.23	435562.2	615041.5	192100.0	287092.9	31901.8	65500.0
47	59.49	423539.5	614645.9	192100.0	274851.9	31883.2	65500.0
48	60.76	416685.0	609411.7	192100.0	266210.0	29430.2	62122.9
49	62.03	387979.6	608712.5	192100.0	262100.9	26961.7	58107.4
50	63.29	370702.2	602043.9	192100.0	240766.3	25943.7	52821.7
51	64.56	364553.9	599168.3	192100.0	240121.9	25341.5	51786.1
52	65.82	363420.0	587413.9	192100.0	227083.0	24143.8	51354.4
53	67.09	361260.8	578221.4	191760.7	225033.9	20108.1	46759.0
54	68.35	355314.7	566941.4	183093.6	209918.6	20050.7	44985.5
55	69.62	346220.3	566885.7	178851.5	203066.7	17937.8	40973.2
56	70.89	343670.1	555473.6	178835.2	195529.8	17636.3	38802.5
57	72.15	336289.1	548305.5	174059.9	190049.7	16439.7	38628.0

58	73.42	335322.6	507267.6	170793.1	178571.1	16034.1	36639.2
59	74.68	322044.8	502695.0	168050.4	145621.0	15307.3	36501.4
60	75.95	319088.0	495810.0	167826.8	142325.5	15125.0	32314.8
61	77.22	304340.3	476233.8	166715.2	133993.9	12269.5	27749.0
62	78.48	302215.2	475856.8	162272.2	133905.7	10752.3	25219.1
63	79.75	295437.6	472514.9	155630.3	99619.4	9611.7	23253.4
64	81.01	286757.6	459187.9	151035.5	94159.3	6761.7	20836.8
65	82.28	230606.3	448971.4	148816.0	80315.6	6287.0	19122.0
66	83.54	222747.2	446012.2	144563.8	75715.6	5737.7	17533.4
67	84.81	209412.5	445196.0	136611.3	55644.9	5393.4	16010.1
68	86.08	192631.8	442442.1	132808.9	50910.2	4594.6	14863.1
69	87.34	180173.9	440895.1	129152.5	50335.0	3111.8	14718.9
70	88.61	155930.3	436263.7	128419.6	50246.4	1564.9	14301.6
71	89.87	124689.6	422789.4	120275.7	24789.0	1461.3	13406.7
72	91.14	120239.4	422673.8	118610.2	23817.6	1244.0	10621.8
73	92.41	62341.8	410702.5	118551.8	22214.9	1163.5	6947.0
74	93.67	48174.6	409227.9	113769.2	16518.1	1030.7	6886.0
75	94.94	37796.9	402453.2	110544.0	12175.4	502.5	1857.0
76	96.20	2840.5	400281.0	104043.0	9569.7	58.1	1530.2
77	97.47	2537.4	398955.1	104043.0	8877.6	19.7	1256.0
78	98.73	349.8	379066.9	77594.4	2393.3	0.0	240.0

Parameter ID in 7FFA record field 2 allows selection one of the following variables for the analysis: naturalized flow (ID=1), regulated flow (ID=2), reservoir storage volume (ID=3), and reservoir storage volume adjusted for excess flow (ID=4). ID option 4 is employed in this example. However, as explained below, five of the six reservoirs have no excess flow adjustments, meaning ID options 3 and 4 generate identically the same results. Possum Kingdom (PK) is the only reservoir with excess flows and thus the only reservoir with frequency analysis results affected by the choice between ID options 3 versus 4.

Probability distribution functions, such as the log-Pearson type III, are applicable to homogeneous datasets representing the behavior of a particular phenomenon. Annual peak daily naturalized stream flow volumes represent a much more homogeneous data set for which the log-Pearson type III distribution is likely more applicable or accurate than for regulated stream flows or reservoir storage. The annual series of peak regulated flow and peak storage volume reflect the effects of reservoir operations and water management. Reservoir operations differ greatly between conservation pool operations, flood control pool operations, and surcharge operations.

A dataset of maximum annual reservoir storage contents is subject to non-homogeneity associated with switching between regular and emergency flood operations as well as between conservation pool and flood control pool operations. *Emergency operations* refers to situations in which flood waters have completely filled the storage capacity of the flood control pool. In this example, emergency operations of the flood control reservoirs are modeled simply by allowing outflow to equal inflow whenever the flood control pool storage capacity is exceeded.

Five of the six reservoirs have large designated flood control pools with releases controlled by gate operations based on flows at downstream controlled. The "uncontrolled" flood control pool of Possum Kingdom Reservoir (PK) is surcharge storage modeled with *FV/FQ* records. The surcharge storage in Possum Kingdom Reservoir is exceeded in many days of the 1940-2017 *SIMD* simulation. The flood control pools of the five other reservoirs happen to never be overtopped (exceeded) during the 1940-2017 simulation, and thus 7FFA record ID options 3 and 4 generate identically the same frequency statistics. Results vary significantly for Possum Kingdom Reservoir with option 3 versus option 4.

Flood frequency analyses with variable option 4 selected in 7FFA record field 2 is designed to approximate a reservoir with infinite flood control storage capacity using the concept of "excess flows" for purposes of dealing with this non-homogeneity issue. The term *excess flow* is adopted to refer to the cumulative outflows from a reservoir throughout each year when the controlled flood control storage capacity is full. *SIMD* records excess flows in the last column of the AFF file. With option 4 entered in 7FFA record field 2, *TABLES* performs the frequency analyses with the sum of storage plus excess flow. This represents a reservoir with infinite flood control storage capacity with releases controlled only by the regular operating rules in effect when the storage level is below the top of flood control pool.

The storage frequency analysis is repeated with *HEC-SSP* in Example 9.6. *HEC-SSP* performs log-Pearson III flood frequency computations that will reproduce the results obtained with the *TABLES* 7FFA routine for the metrics that are common to alternative programs. *HEC-SSP* also computes confidence limits, outlier adjustments, and expected probability adjustments which are not provided with the *TABLES* 7FFA record. The *HEC-SSP* outlier and expected probability adjustments can significantly affect results. *HEC-SSP* also plots the frequency analysis results.

With a skew coefficient of zero, the log-Pearson III and log-normal distributions are the same. The log-normal probability distribution consists of applying the normal probability distribution to the logarithms of the values of the random variable. The skew coefficient is highly uncertain for a small sample size, more so than for the mean and standard deviation. Options for improving skew coefficient estimates activated by the 7FFA record field 6 parameter SKEW are explained in the *WRAP Users and Reference Manuals*. *HEC-SSP* includes similar features.

HEC-DSSVue and *HEC-SPP* frequency graphs provide a mechanism to compare the relative closeness-of-fit for a particular dataset of the normal, log-normal, and log-Pearson III analytical probability distribution functions. Closeness of the analytical probability curves to the Weibull plotting positions represents closeness in modeling the random variable. *HEC-SPP* frequency plots are illustrated by Figures 9.10 through 9.15 of Example 9.6. Comparisons between alternative frequency analysis methods are discussed in Example 9.6.

HEC-DSSVue includes options for two different types of probability graphs. The frequency curves of Figure 9.7 in Example 9.2 were created with the feature accessed through the following option path: *Tools/Math Functions/Statistics/Duration Analysis/Display/Plot*. *HEC-DSSVue* also prepare frequency graphs similar to Figures 9.10 through 9.15 of Example 9.6 but without adjustments or confidence limits. The *HEC-DSSVue* frequency plot option is activated through the option path: *Tools/Math Functions/Statistics/Frequency Plot*.

Example 9.5 – Flood Frequency Analysis with *HEC-DSSVue*

HEC-DSSVue is the interface for the Hydrologic Engineering Center (HEC) Data Storage System (DSS). The comprehensive array of time series data management capabilities provided by *HEC-DSSVue* includes basic statistics and frequency analyses. The objective of Examples 9.2 and 9.5 is to illustrate the fundamentals of the *HEC-DSSVue* statistics capabilities which can be applied with any of the time series found in WRAP input and output datasets for a wide range of applications. Example 9.5 is a *HEC-DSSVue* version of the Example 9.3.

Example 9.5 employs the Weibull formula (Equation 9.2) to perform *HEC-DSSVue* frequency analyses of peak annual reservoir storage contents. *HEC-DSSVue* also includes options for developing frequency plots based on the log-Person type III or log-normal probability distributions and the Weibull formula. However, *HEC-SSP* provides more detailed frequency tables and plots, which are illustrated in Example 9.6.

The *HEC-DSSVue* main screen is shown in Figure 8.1 of the preceding Chapter 8. Clicking *Tools* in the menu bar accesses *Math Functions* along with other choices. Clicking *Math Functions* accesses the following menu tabs: *Arithmetic*, *General*, *Time Functions*, *Hydrologic*, *Smoothing*, and *Statistics*. Example 9.5 employs features accessed through the *Time Functions* and *Statistics* menus.

Within the *Time Functions* menu, the operator "*Min/Max/Avg/...over Period*" accesses the following function types: *interpolate*, *maximum*, *minimum*, *average*, *accumulation*, *volume*, *integration*, and *number of valid data during period*. Any new time period can be specified. The analysis of 7-day low flows in the earlier Example 9.2 employs the *average* and *minimum* functions in changing from daily to annual. The analysis of peak annual storage contents in Example 9.5 uses the *volume* and *maximum* functions in changing from daily to annual.

Statistical analysis operations are accessed through *Tools/Math Functions/Statistics*. Within the *HEC-DSSVue Statistics* menu choices, the type options include: *basic*, *linear regression*, *cyclic analysis*, *duration analysis*, and *frequency plot*. The examples employ the *basic* and *duration analysis* routines. The terms *duration analysis* and *frequency analysis* are used interchangeably to refer to the frequency analysis computations presented here.

The *basic statistics* metrics tabulated in Table 9.12 include the number of values, number of missing values, minimum and maximum, mean, and standard deviation for the time series quantities in a selected DSS record. These statistics are for the maximum storage contents in each reservoir in each of the 78 years of the *SIMD* daily simulation. Values of means, standard deviations computed with *HEC-DSSVue* are identical to the values computed with *TABLES*.

Table 9.12
Basic Statistics for Annual Maximum Reservoir Storage Contents

Reservoir	PK	Whitney	Waco	Belton	Georgetown	Granger
Number of valid values	78	78	78	78	78	78
Mean (acre-feet)	431,846	619,599	197,616	341,051	30,825	60,664
Standard Deviation (ac-ft)	180,976	157,895	66,379	215,102	19,619	35,261
Minimum (acre-feet)	350	379,067	77,594	2,393	0.0	240
Maximum (acre-feet)	591,146	1,173,138	446,391	922,042	105,599	196,524

The *duration analysis* assigns probabilities to each of the quantities in selected DSS time series records using the Weibull formula (Eq. 9.2). All values can be tabulated or alternatively a standard 23 point tabulation option can be selected. Quantities are interpolated for the 23 pre-set probabilities listed in the first column of Table 9.13. The storage volumes with these exceedance

probabilities were computed within the *duration analysis* feature, exported to Microsoft Excel for further formatting, and transferred to Table 9.13 created in the Microsoft Word document. *TABLES* uses Eq. 9.1 and *HEC-DSSVue* uses Eq. 9.3 for the frequency computations.

Table 9.13
Weibull Exceedance Frequency Relationships for Peak Annual Storage for Example 9.5

Reservoir	PK	Whitney	Waco	Belton	Georgetown	Granger
Top of Flood Control	665,400	2,000,000	726,400	1,091,320	130,800	244,200
Conservation Capacity	570,240	627,100	192,100	457,600	37,100	65,500
P = [m/(N+1)]100%	Annual Maximum End-of-Day Storage Contents (acre-feet)					
2%	591,051	1,156,276	436,027	915,267	83,945	150,419
5%	587,787	921,966	361,499	678,619	57,558	112,949
10%	585,650	771,184	265,731	602,337	51,748	104,792
15%	582,405	727,481	234,849	524,031	47,354	97,387
20%	580,143	697,961	214,520	489,463	43,947	85,830
30%	576,022	646,626	195,208	461,025	40,422	75,362
40%	572,241	627,986	192,100	457,600	37,681	67,143
50%	534,175	627,100	192,100	393,010	37,100	65,500
60%	420,798	612,552	192,100	271,395	30,902	64,149
70%	345,455	563,462	178,847	200,806	17,847	40,322
80%	293,702	469,850	154,711	98,527	9,042	22,770
85%	206,895	444,783	136,041	54,935	5,274	15,838
90%	124,245	422,778	120,109	24,692	1,440	13,128
95%	36,049	402,345	110,219	12,045	480	1,841
98%	1,619	390,602	92,935	6,154	11.0	829

Example 9.6 – Flood Frequency Analysis with HEC-SSP

The *HEC-SSP Statistical Software Package* is available from the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (<http://www.hec.usace.army.mil/>). The public domain software and users manual [19] can be downloaded from the HEC website along with *HEC-DSSVue* and other HEC computer tools and accompanying manuals. *HEC-SSP* performs frequency analyses with the results presented both in tables and graphs as illustrated by the present Example 6.6 which repeats the earlier Example 9.4 that employs the *TABLES* 7FFA routine. *HEC-SSP* is composed of the following components.

- A general frequency analysis component applies the log-Pearson type III, Pearson type III, log-normal, or normal probability distribution functions to perform frequency analyses for annual series of peak flows or other variables. The Weibull formula is also applied. This component is employed in Example 9.6 for frequency analyses of annual peak reservoir storage contents.
- A Bulletin 17B or 17C flood flow frequency component applies the log-Pearson type III probability distribution to annual series of peak stream flows following standard procedures outlined in the 1982 USGS Bulletin 17B entitled *Guidelines for Determining Flood Flow Frequency* and its 2017 Bulletin 17C update. This option may also be applied to Example 9.6.

- A volume frequency analysis component is designed for analyzing daily stream flow 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. This component can be employed to perform the annual 7-day low flow analyses of Examples 9.1 and 9.2.
- A duration analysis component shows the percent-of-time that a hydrologic variable exceeds specified values. This feature is similar to the *TABLES* 2FRE and 6FRE frequency routines and *HEC-DSSVue* duration analysis component.
- A coincident frequency analysis component develops an exceedance frequency relationship for a variable as a function of two other variables. For example, flood flows on different tributaries.
- A curve combination analysis component combines frequency curves from multiple sources.

HEC-SSP reads input datasets and stores analysis results in a variety of different optional user-specified file formats that include DSS files, text files, Microsoft Excel spreadsheets. *HEC-SSP* can be employed to directly download observed flow daily flows, annual peak flows, and other data from the National Water Information System (NWIS) website maintained by the U.S. Geological Survey (USGS) into a DSS file created by *HEC-SSP*.

HEC-DSSVue and *HEC-SPP* have similar file management options. Both include a feature for downloading data from the USGS NWIS. However, due to recent modifications to the NWIS website made by the USGS, the *HEC-DSSVue* feature for accessing the data is not currently functional. *HEC-SSP* has been updated to function with the new modified USGS NWIS website.

HEC-DSSVue, *HEC-SSP*, and the WRAP programs are conveniently used in combination. These programs all read and create DSS files. The programs are also conveniently employed in combination with Microsoft Excel, with data exchanged through DSS files or optionally text files.

The primary advantage of *HEC-SSP* over *HEC-DSSVUE* and the WRAP program *TABLES* is the comprehensive detailed *HEC-SSP* flood frequency analysis capabilities. *HEC-SSP* focuses largely on flood flow frequency analyses but also provides other capabilities. Some of the flood analysis and essentially all of the analyses not related to floods are also provided by *HEC-DSSVue* and *TABLES*. *HEC-DSSVue* and *TABLES* contain a variety of features not found in *HEC-SSP*.

The USGS Bulletin 17B/17C flood flow frequency component of *HEC-SSP* is designed specifically for log-Pearson type III frequency analyses of flood flows on streams and rivers. The log-Pearson III stream flow frequency computations are supplemented by adjustments and auxiliary analysis features. The Weibull formula is also applied. Tables and plots are produced.

The general frequency analysis component includes options for applying the log-Pearson type III, Pearson type III, log-normal, and normal probability distribution functions, and the Weibull formula. Frequency tables and plots are generated. Flood flows can be analyzed with either the general or Bulletin 17B/17C components. However, the general component is not limited to a particular random variable. The ideal hydrologic random variable for the log-Pearson III distribution is annual instantaneous peak river flow rates. As discussed later, the most appropriate WRAP variable for the Example 9.6 methodology is annual peak daily naturalized flow rates. However, the methodology is also applicable to other variables including peak annual reservoir storage.

Compilation of Annual Peak Storage Contents Time Series for the Six Reservoirs

HEC-DSSVue is used in this example to develop an annual series of peak storage contents in acre-feet for each of the six reservoirs from the daily *SIMD* simulation results recorded in the DSS output file. The following option path is employed *Time Functions/Min/Max/Avg/...over Period/Volume/Maximum/* with *Year* selected for the period. The six annual series are plotted with *HEC-DSSVue* and copied onto this page as Figure 9.9. The *SIMD* generated AFF file (Example 9.4) provides an alternative approach for compiling a peak annual storage data series.

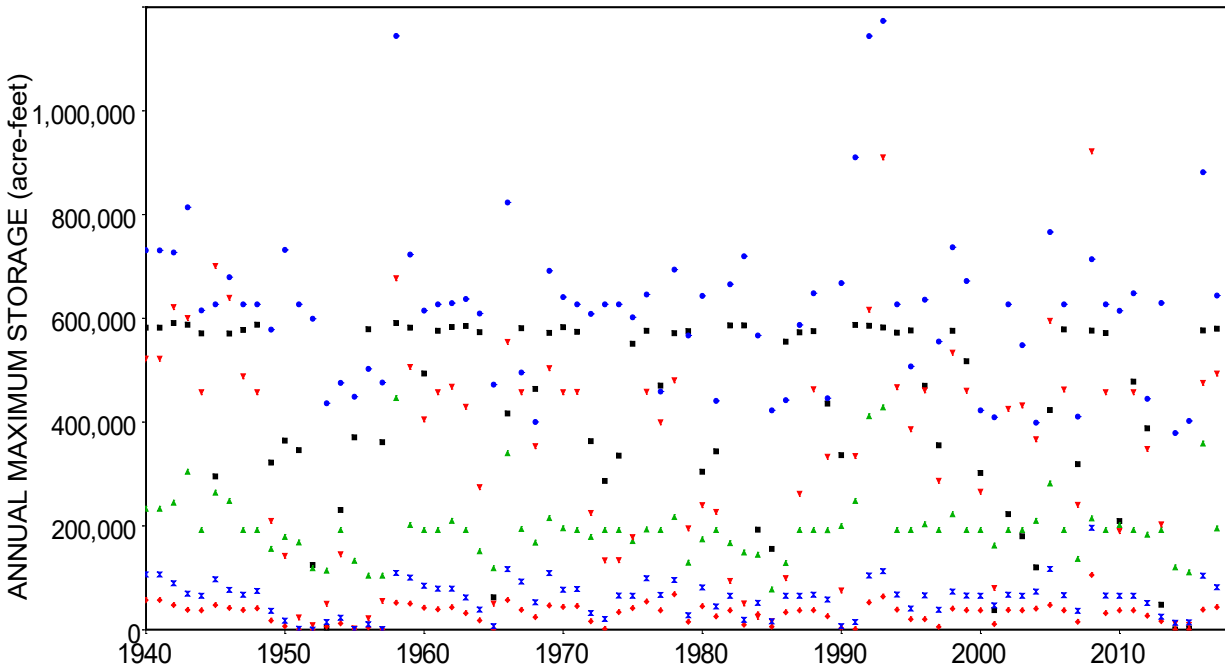


Figure 9.9 Peak Storage Contents in Each Year of the 1940-2017 Daily *SIMD* Simulation in Possum Kingdom (black squares), Whitney (blue circles), Waco (green triangles), Belton (red triangles), Georgetown (red diamonds), and Granger (blue triangles) Reservoirs

The HEC-SSP flood frequency analysis routines require that DSS records be in irregular time interval format. All of the other uses of DSS files in the examples of this report, including all *SIM* and *SIMD* input and output DSS files, use regular interval data. With a set constant time interval and known beginning date and time, the dates and times for all data in the regular data series are automatically defined. Conversely, with irregular interval DSS records, the DSS software explicitly assigns each data value a date and time. The six series of 78 annual values are compiled in regular-interval format as described in the preceding paragraph. The dataset is then quickly and easily converted to irregular format with the *HEC-DSSVue* feature activated through the following option path: *Tools/Math Functions/Time Functions/Regular to Irregular*.

HEC-SSP Flood Frequency Analyses

Frequency analyses are performed with *HEC-SSP* for the 78 annual maxima of daily storage contents of the six reservoirs. The storage-frequency relationships for the six reservoirs

are summarized in Table 9.14. The Example 9.6 quantities in Table 9.14 computed with *HEC-SSP* correspond to the Example 9.4 quantities in Table 9.11 computed with the *TABLES 7FFA* routine. These metrics provide estimates of the storage levels that have specified probabilities of being exceeded in any year.

Table 9.14
Log-Pearson Type III Probability Relationships for Peak Annual Storage for Example 9.6

Reservoir	PK	Whitney	Waco	Belton	Georgetown	Granger
Top of Flood Control	665,400	2,000,000	726,400	1,091,320	130,800	244,200
Conservation Capacity	570,240	627,100	192,100	457,600	37,100	65,500
Percent Chance						
<u>Exceedance</u>	<u>Annual Maximum End-of-Day Storage Contents (acre-feet)</u>					
0.2%	674,596	1,317,594	496,140	1,007,887	64,411	129,558
0.5%	674,020	1,198,903	443,116	986,239	64,346	128,462
1.0%	672,939	1,111,215	404,388	960,176	64,213	126,972
2.0%	670,540	1,024,760	366,611	921,151	63,888	124,479
5.0%	662,325	911,044	317,604	838,633	62,653	118,426
10.0%	646,702	823,801	280,595	740,379	60,100	110,113
20.0%	610,873	732,762	242,591	596,073	53,960	96,007
50.0%	474,706	594,122	186,132	304,998	32,014	60,341
80.0%	280,019	490,595	145,308	103,391	10,038	26,984
90.0%	185,631	447,012	128,531	48,700	3,981	15,130
95.0%	122,443	415,431	116,546	23,570	1,547	8,591
99.0%	46,095	365,160	97,796	4,634	165.0	2,372

Total storage capacities in acre-feet below the top of conservation pool and below the top of flood control pool are tabulated at the top of Table 9.14. The probability estimates in Table 9.14 indicate that the flood control pool storage capacities of the five flood control reservoirs are large enough to contain the 500 year return period (0.2% annual exceedance frequency) flood without overtopping. For example, Whitney Reservoir has a total capacity of 2,000,000 at its designated top of flood control pool elevation. There is an estimated 0.2% likelihood that the maximum storage capacity of Whitney Reservoir will be exceeded in any year.

Frequency curves created with *HEC-SSP* are presented as Figures 9.10, 9.11, 9.12, 9.13, 9.14, and 9.15. The return period in years is the reciprocal of the annual exceedance probability. The storage-frequency relationships tabulated in Table 9.14 are plotted as the red curves. The green dashed lines in the graphs are 5% and 95% confidence limits for the frequency curves. The blue circles in the graphs are quantities computed with the Weibull formula (Equation 9.2). Outliers are blue squares. Though not replicated in Table 9.14, the confidence limits and Weibull formula quantities are tabulated in the tables generated by *HEC-SSP*.

Legend for Figures 9.10 through 9.15

- log-Pearson III computed frequency curve (red solid line)
- - - 5% and 95% confidence limits (green dashed lines)
- Weibull plotting positions (blue circles, Blue squares are outliers.)

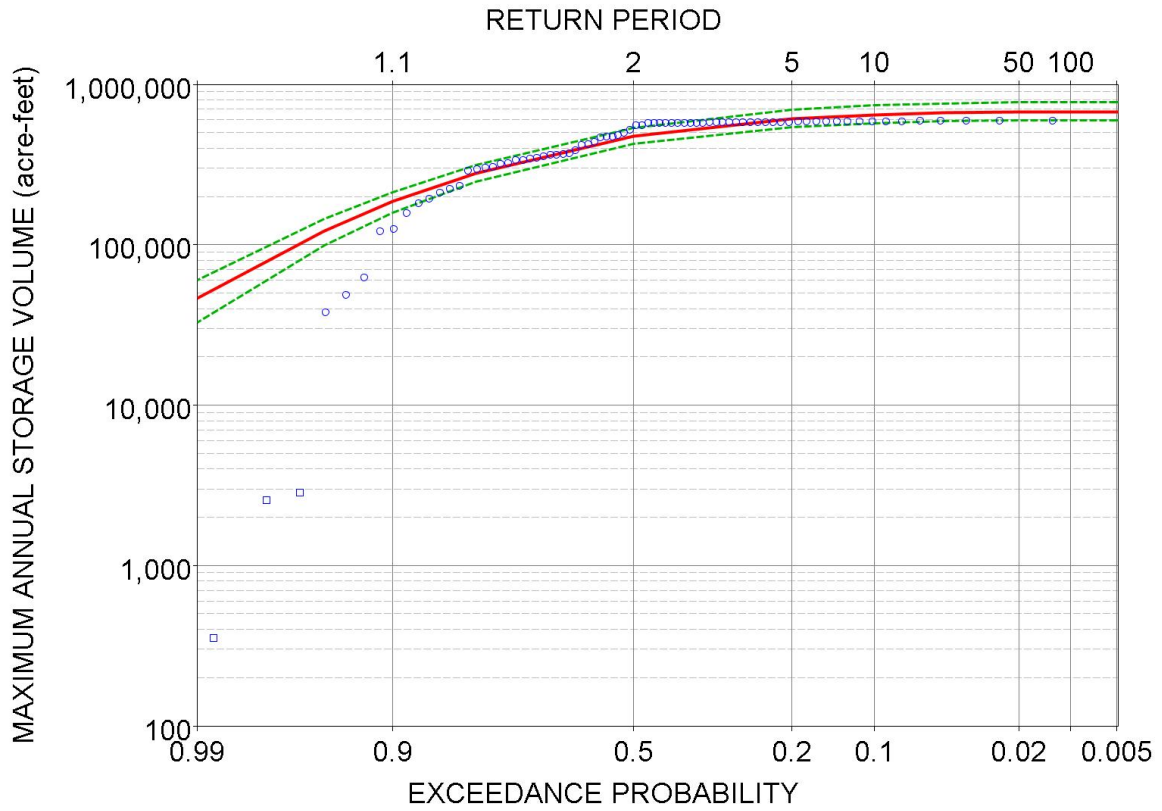


Figure 9.10 Storage Frequency Relationships for Possum Kingdom Reservoir

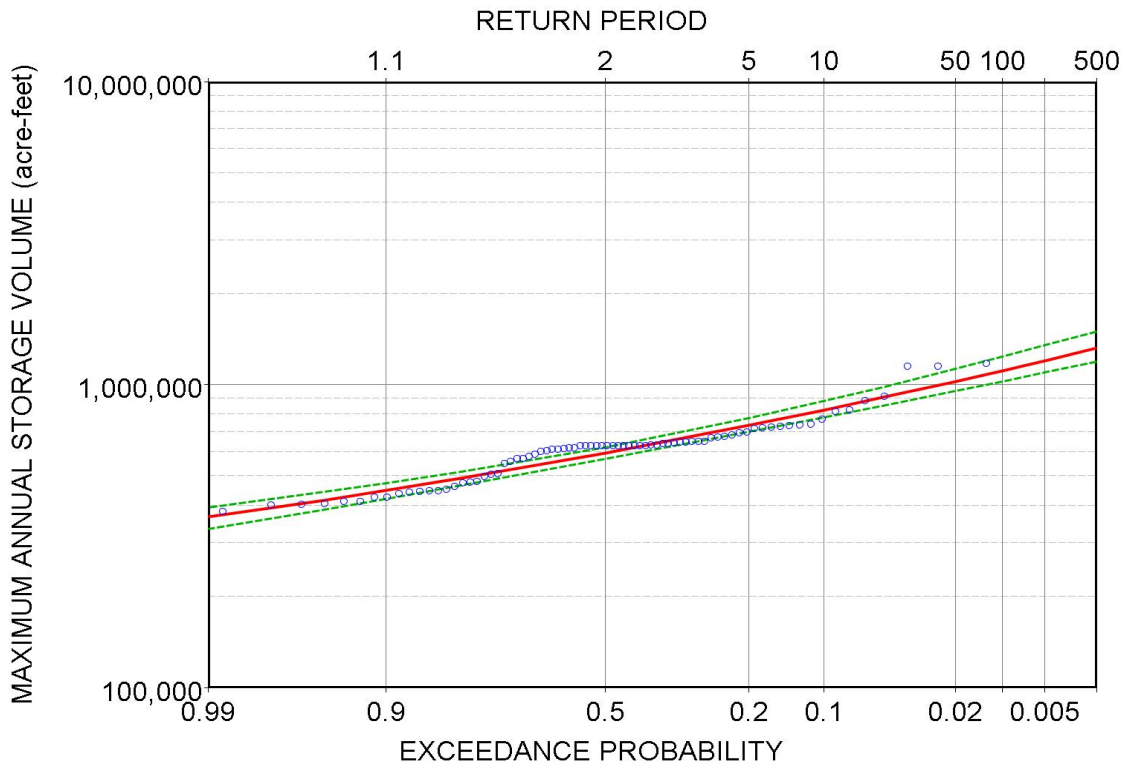


Figure 9.11 Storage Frequency Relationships for Whitney Reservoir

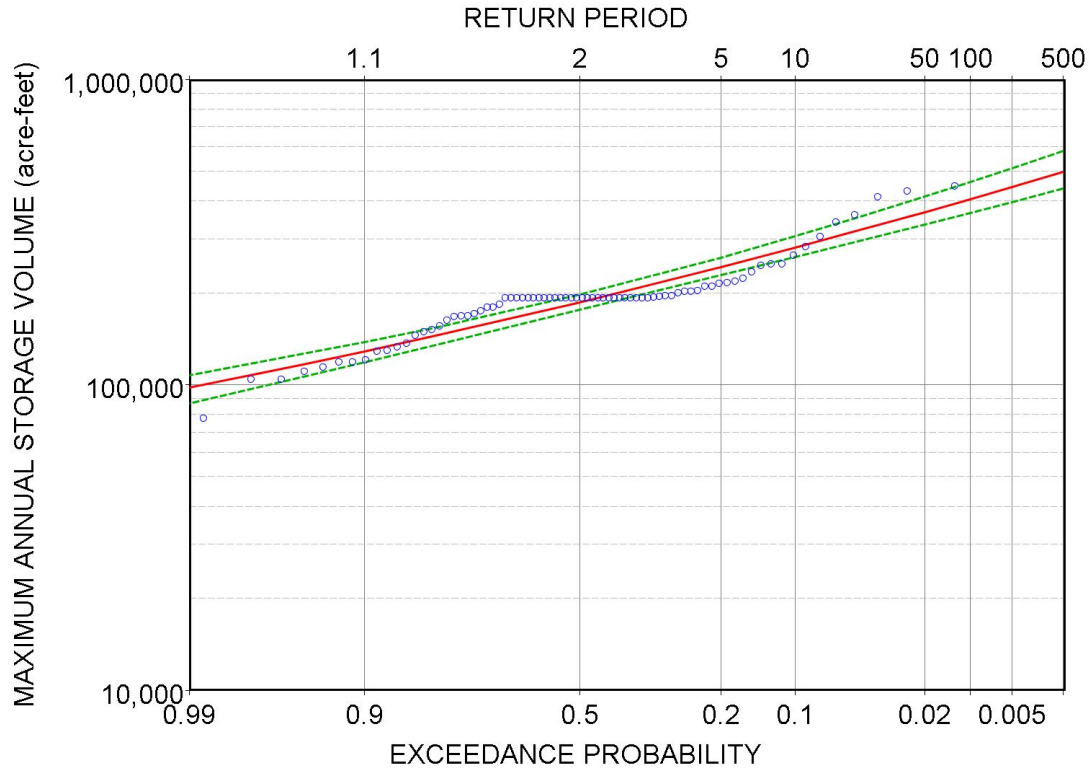


Figure 9.12 Storage Frequency Relationships for Waco Reservoir

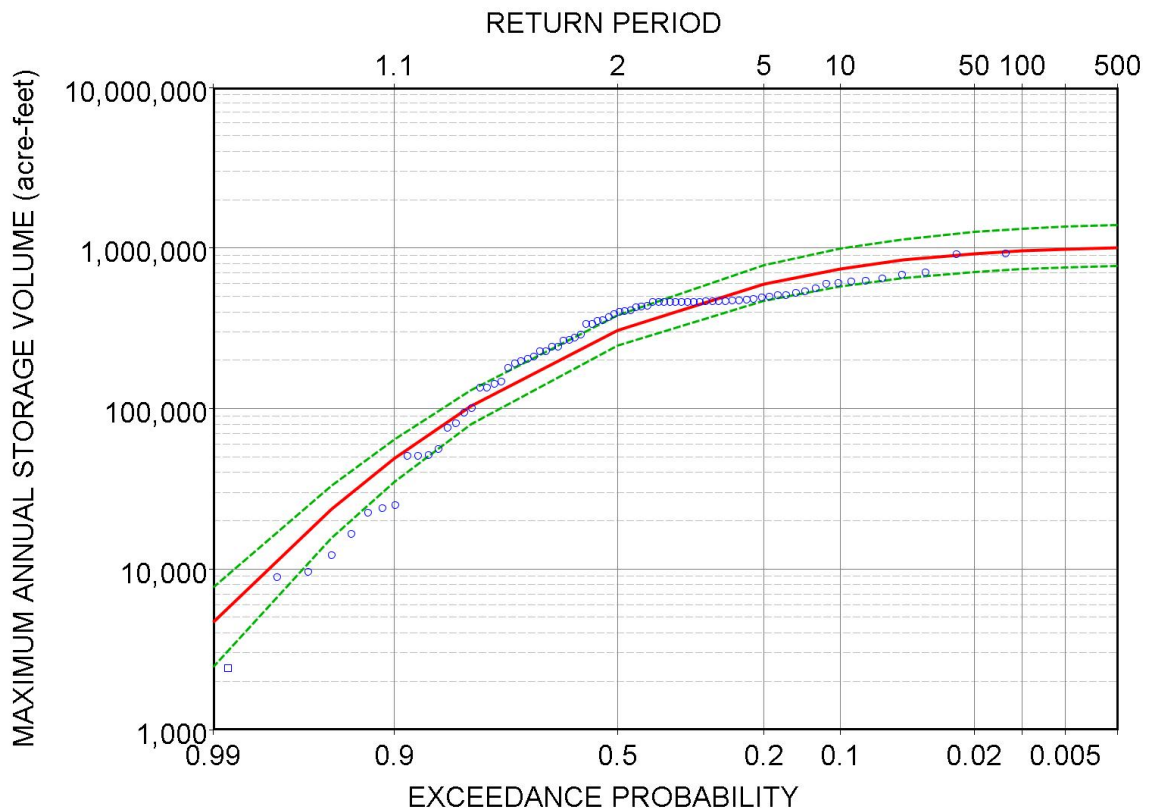


Figure 9.13 Storage Frequency Relationships for Belton Reservoir

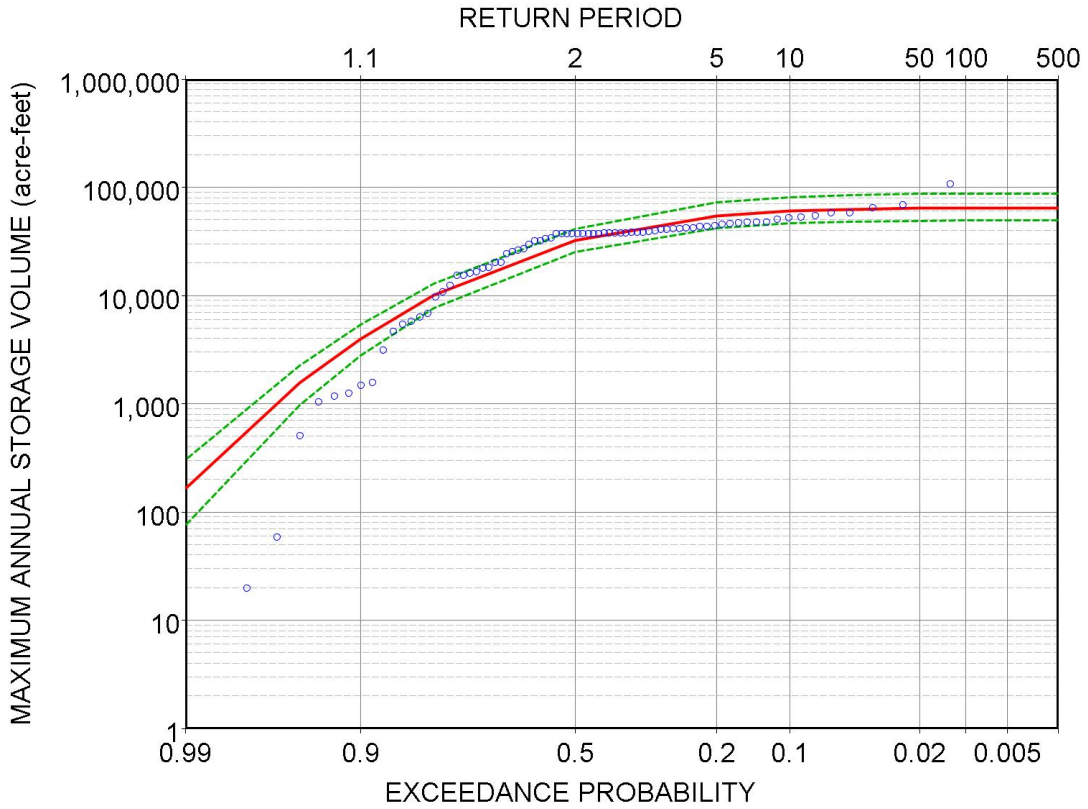


Figure 9.14 Storage Frequency Relationships for Georgetown Reservoir

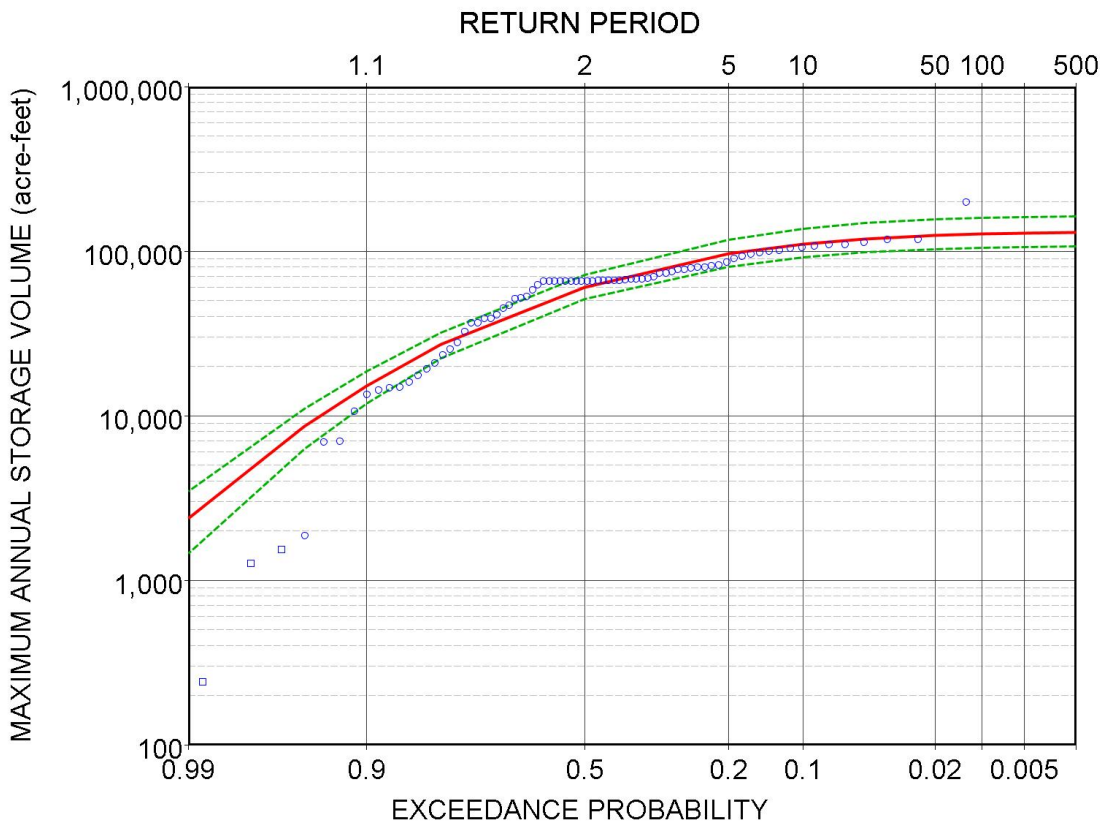


Figure 9.15 Storage Frequency Relationships for Granger Reservoir

Table 9.15
Statistics Used in the Computation of the Log-Pearson III Frequency Curves

Reservoir	PK	Whitney	Waco	Belton	Georgetown	Granger
Mean of Logarithms	5.594	5.779	5.275	5.360	4.316	4.678
Standard Deviation	0.253	0.104	0.133	0.505	0.561	0.377
Skew Coefficient	-2.153	0.323	0.241	-1.541	-2.275	-1.723
Systematic Events	78	78	78	78	78	78
High Outliers	0	0	0	0	0	0
Low Outliers	3	0	0	1	1	3

The statistics listed in Table 9.15 are computed by *HEC-SSP* for use in developing the log-Pearson III frequency relationships in Table 9.14 and Figures 9.10-9.15. Equation 9.4 is employed with the mean and standard deviation (Eqs. 9.5 and 9.6) of the logarithms of the data. The skew coefficient (Eq. 9.7) of the logarithms of the data is used in selecting the frequency factor K (Eq. 9.4) from the Log-Pearson type III probability table. The log-Pearson III frequency factor tables incorporated in *HEC-SSP* and *TABLES* are more detailed and precise than the abbreviated version presented as Table 7.18 of the *WRAP Reference Manual* [1].

HEC-SSP includes default criteria for defining high and low outliers which can be replaced with user-specified criteria. The default criteria are adopted for Example 9.6. As indicated by Table 9.15, none of the 78-year datasets for the six reservoirs have high outliers, but four have either one or three low outliers. Weibull points for low outliers are plotted as blue squares in Figures 9.10-9.15. The low outliers are omitted from the computation of the mean, standard deviation, and skew coefficient. Thus, with three low outliers removed, the log-Pearson III computations for PK and Granger are based on 75 data values. With one outlier removed, the datasets for Belton and Georgetown contain 77 peak annual storage volumes.

The *TABLES* 7FFA record routine does not include adjustments for outliers. With no outliers, the log-Pearson III results for Whitney and Waco are the same with either *TABLES* or *HEC-SSP*. The Weibull probabilities are always the same with *TABLES* 7FFA and *HEC-SPP*.

HEC-SSP frequency tables and plots include 5% and 95% confidence limits for the "computed frequency curve". The computed curve is the red solid line and the confidence limits are green dashed lines in Figures 9.10-9.15. There is a 90% probability that estimated quantities based on a given sample size ($N = 78, 77, \text{ or } 75$) fall within the 5% and 95% confidence limits, assuming no measurement or computation errors in the sample dataset, perfect stationarity over time, and a perfect fit for the random variable to the log-Pearson type III probability distribution.

The reservoir storage versus exceedance frequency relationships tabulated in Tables 9.11 (Example 9.4) and 9.14 (Example 9.6) and plotted in the frequency graphs represent median (50% exceedance) values of the random variable. *HEC-SSP* also computes *expected probability* adjusted quantities that represent expected (mean) values. The optional *HEC-SSP* expected value adjustments are not employed in Example 9.6.

The *HEC-SSP* frequency plots in Figures 9.10 through 9.15 have a normal probability horizontal axis and a logarithmic vertical scale. By definition, the log-normal probability distribution plots as a straight line on a graph with a normal probability horizontal axis and a logarithmic vertical scale. The log-normal distribution is identical to the log-Pearson type III distribution with a skew coefficient of zero. The curvature in the log-Pearson type III plots is due to skewness as modeled by a negative or positive non-zero skew coefficient.

The 78 points computed with the Weibull formula are plotted in Figures 9.10-9.15 as blue circles, except the low outliers are blue squares, and also tabulated by *HEC-SSP*. These same Weibull plotting positions computed by the *TABLES 7FFA* routine are tabulated in Table 9.11.

The plots of Figures 9.10 through 9.15 provide a qualitative visualization of the closeness-of-fit between Weibull versus log-Pearson III probability estimates for these datasets. The match or lack thereof between the computed curve and Weibull plotting positions is an indication of the validity or accuracy of the log-Pearson type III distribution in modeling the relationship between annual maximum reservoir storage contents and exceedance probability.

Probability distribution functions such as the log-Pearson type III are applicable to homogeneous datasets. The datasets of maximum annual reservoir storage volumes reflect non-homogeneity associated with switching between conservation pool, flood control pool, and surcharge operations as the storage contents fluctuate. The storage levels tend to be at or near top of conservation pool much of the time as reflected by the flat portions of the frequency curves. Outflow equals inflow whenever the flood control pool storage capacity is exceeded in the *SIMD* simulation. However, storage contents happen to never exceed the flood control pool capacity of the five flood control reservoirs during the 1940-2017 simulation. The surcharge storage in Possum Kingdom (PK) Reservoir is exceeded often during the 1940-2017 *SIMD* simulation.

Annual peak daily naturalized stream flow volumes represent a much more homogeneous random variable for which the log-Pearson type III distribution is likely more applicable or accurate than for regulated stream flows or reservoir storage. *SIMD* simulated regulated flows are typically more homogeneous than reservoir storage contents though also affected by reservoir operations and other water management activities included in the model.

Figures 9.10 through 9.15 demonstrate that the log-Pearson III distribution is not an especially close fit for annual peak storage in the six reservoirs. With a sample size N of 78 years, the Weibull formula is probably the best approach for assigning exceedance probabilities to reservoir storage levels with return periods of about 75 years or less (annual exceedance probabilities of 0.013 or greater). The log-Pearson III analysis facilitates extrapolation to extreme flood storage levels with return periods of perhaps 100 years or greater (annual exceedance probabilities of 0.01 or less) which approach or exceed the flood control pool storage capacity.

Relative frequency analyses based on Equations 9.1 or 9.2 employed with either *TABLES 2FRE*, *6FRE*, or *7FFA* records or the *HEC-DSSVue* duration analysis feature is the optimal strategy for most WRAP-related frequency analysis applications. Log-Pearson III probability distribution based methods are standard accepted practice for assigning annual exceedance probabilities for extremely high flood flows and other variables representing hydrologic or other extremes. The log-normal distribution is also commonly used with various hydrologic variables.

CHAPTER 10 GENERAL OVERVIEW SUMMARY

A primary motivation for development of the daily features of WRAP has been to expand capabilities for incorporating environmental instream flow standards into water availability modeling. Converting monthly water availability models (WAMs) to daily and adding environmental flow standards (EFS) are a central focus of this manual. However, the daily WRAP is a flexible generalized modeling system that can be employed in a broad spectrum of applications.

Most of the modifications to the WRAP programs between the May 2019 and July 2022 versions focused on the daily simulation model *SIMD*, as described in the *WRAP Additions and Revisions Report* [21]. The *SIMD* simulation results presented in Chapters 7, 8, and 9 were generated with the May 2019 version of *SIMD*. As noted at the beginning of Chapter 7 (page 133), simulation results produced with the July 2022 *SIMD* are a little different due to modifications since May 2019, primarily related to *FV* and *FQ* records as applied to modeling surcharge storage at Possum Kingdom Reservoir.

Daily WRAP Modeling System

The components of the daily WRAP modeling system are outlined in Table 10.1. The daily *SIMD* simulation model includes all the modeling capabilities of the monthly *SIM* simulation model, adjusted if and as necessary for a daily computational time step. *SIMD* includes additional disaggregation, routing, and forecasting features relevant for dealing with complexities in a daily model that do not occur in a monthly simulation. The daily computational time step provides opportunities not possible with a monthly time step to add reservoir flood control operations and high pulse flow components of environmental flow standards to the model.

Table 10.1
Daily WRAP Modeling System

Simulation of River/Reservoir Water Management/Use System with *SIMD*

- *SIM* Monthly Simulation Capabilities Replicated in *SIMD*
- Additional *SIMD* Capabilities Not Available in *SIM*
 1. Monthly-to-Daily Disaggregation of Naturalized Stream Flows
 2. Monthly-to-Daily Disaggregation of Other Quantities
 3. Routing Flow Changes Caused by Water Rights
 4. Stream Flow Forecasting for Assessing Water Availability
 5. Additional Negative Incremental Flow Option and other Adjustments
 6. Simulation of Reservoir Operations for Flood Control
 7. Tracking High Pulse Flow Events for Environmental Flow Standards

Management/Analysis of *SIMD* Input Datasets with *TABLES* and *HEC-DSSVue*

Management/Analysis of *SIMD* Simulation Results with *TABLES* and *HEC-DSSVue*

Calibration of Routing Parameters Using *DAY* or *DAYH*

The *SIMD* simulation model is the central component of the daily modeling system. *TABLES* and *HEC-DSSVue* provide a variety of capabilities for managing, organizing, and analyzing *SIMD* input datasets and simulation results. Alternative methods for calibrating flow routing parameters are implemented in the WRAP programs *DAY* and *DAYH*. The concepts and methodologies employed in the WRAP modeling system are documented by the *Reference Manual* and this auxiliary *Daily Manual*, which covers the expanded daily modeling features not covered in the *Reference Manual*. The logistics of preparing input records shared by *SIM* and *SIMD* and additional *SIMD*-only records are explained in Chapters 3 and 4, respectively, of the *Users Manual*. Logistics of using *TABLES* and *HEC-DSSVue* with either daily or monthly input or output datasets are covered in Chapters 5 and 6 of the *Users Manual*. The WRAP programs *DAY* and *DAYH* are documented in Appendices A and B of this *Daily Manual*.

Either *SIMD* or *SIM* can be employed to perform a monthly simulation with an input dataset prepared for a monthly simulation that contains no input records that are applicable only to *SIMD*. The monthly *SIM* can also be employed to perform a monthly simulation with an input dataset prepared for a daily simulation that contains input records that are applicable only to *SIMD*. *SIM* simply skips over daily-only *SIMD* records. However, a monthly (no *JT* record) *SIMD* simulation terminates with an error message if a daily-only *SIMD* input record is found in the DAT file.

A daily simulation is activated by a *JT* record. The *JT* record is the only additional input record required to convert a monthly *SIM* input dataset to a daily *SIMD* input data. A daily *SIMD* simulation activates various computations that are not included in *SIM*. However, for a daily *SIMD* simulation with a *JT* record with all blank fields and no other *SIMD*-only input records, the daily simulation proceeds with defaults activated for all necessary daily-only input parameters. The daily input DIF file is optional, and routing is simply not performed in a daily simulation if no DIF file with routing parameters is provided. *SIMD* capabilities listed in Table 10.1 are a series of optional modeling features that can be added singly or in combination to convert a monthly WAM to daily. Likewise, for a river basin with no pre-existing monthly WAM, a daily *SIMD* input dataset is created based on selecting relevant options from a flexible array of modeling methodologies.

Recommended Daily *SIMD* Simulation Methods

Much of the complexity of both *SIM* and *SIMD* are due to the models containing multiple optional alternative methods for performing the same tasks. A choice of optional methodology leads to another list of choices of options for implementing that selected methodology. *SIMD* is a very complex model that can be greatly simplified by adopting recommended standard options. A much less complicated version of *SIMD* is embedded within the very complex *SIMD*. The simpler *SIMD* model is employed simply by ignoring all options except the set of recommended options.

Several *SIMD* modeling tasks are listed in the first column of Table 10.2. Multiple alternative approaches are provided in *SIMD* for performing each of these tasks. Methods recommended for most typical WAM applications are listed in the second column of Table 10.2. *SIMD* is greatly simplified by simply ignoring the third column of Table 10.2. The series of daily modeling examples presented in Chapters 7, 8, and 9 expand the monthly WAM introduced in the *Fundamentals Manual*. For the tasks listed in Table 10.2, the examples in Chapters 7, 8, and 9 of this *Daily Manual* use only the methods listed in the second column. The options listed in the third column of Table 10.2 are not employed in these examples.

Table 10.2
Recommended *SIMD* Simulation Options

Modeling Function	Recommended Methods	Other Options
time series input file	DSS file	FLO, EVA, FAD, TSF, HIS files
routing flow changes	lag and attenuation	Muskingum routing
routing parameter calibration	<i>DAY</i> statistical method	<i>DAYH</i> optimization options
negative incremental flows	NEGINC option 6 without or option 7 with forecasting	NEGINC options 1, 2, 3, 4, 5, 8
flow disaggregation	default DFMETH option 4	DFMETH options 1, 2, 3
target disaggregation	Uniform	<i>JU</i> and <i>DW</i> record DND or ND
other water right options	use only monthly options	<i>DW</i> and <i>DO</i> record daily options

For most typical water availability modeling (WAM) applications of *SIMD*, an input dataset implementing the methods recommended in the second column of Table 10.2 will provide the optimal simulation model. However, model-users should also consider the other options listed in the third column of Table 10.2 in their research studies or modeling applications dealing with particular situations and issues that would so warrant. The concepts and computational methods employed in all of the options are explained in detail in the preceding chapters of this report.

The lag and attenuation method listed in Table 10.2 is definitely the recommended routing option if routing is adopted. However, the best option for many applications may be no routing at all, meaning either no routing *RT* records are included in the DIF input file or the no routing NORT option on the *JU* is employed to deactivate the *RT* records. Results for alternative simulations with and without routing can be compared. As discussed later in this chapter, without *RT* record routing, there is no reason to activate forecasting on the *JU* record. Forecasting should be employed only if routing is employed. The roles and relative effects of the various daily features that may be added to the simulation are further summarized in the following sections of this chapter.

Daily Versus Monthly Models

Computer simulation models are simplified approximations of real-world systems designed to provide meaningful information for relevant types of modeling and analysis applications. Actual real-world stream flow and other variables simulated in water availability modeling fluctuate continuous over time. Simulation model computations dealing with continuously varying variables are necessarily performed based on fixed computational time intervals. The monthly *SIM* completely ignores within-month variability. Both *SIMD* and *SIM* completely ignore within-day hourly or continuous instantaneous variability which can be relevant for certain modeling applications and situations, such as simulating flood events resulting from intense rainfall on relatively small watersheds.

The effects of computational time step choice on simulation results vary with different water management modeling situations and applications. Flood control reservoir operations, high pulse environmental flow requirements, and the interactions between environmental flow requirements and flood control operations are key aspects of water management that clearly can

be modeled much more accurately with a daily WAM than with a monthly WAM. Daily models are required for modeling both the high flows pulse components of environmental flow standards and reservoir operations during floods due to the extreme variability characteristic of stream flow.

Either monthly or daily WAMs may provide more accurate assessments of water supply availability/reliability depending on the situation. The accuracy of modeling water supply capabilities may or may not be improved by converting from a monthly to a daily WAM. A monthly WAM may be more accurate than a daily WAM in accessing water availability for water supply due to: the complexities of streamflow translation and attenuation modeled by routing and forecasting; disaggregation and associated limitations on available stream flow and water use data; and other aspects of daily modeling. Daily modeling requires major additional input data compilation efforts and is significantly driven by data availability.

The Texas WAM System is appropriately and effectively constructed based on a monthly computational time step. The month is the optimum time interval for the WAM System. However, environmental flow standards can be modeled much more accurately using a daily interval. In general, all components of environmental flow regimes can be modeled more accurately with a daily than with a monthly model. However, improved accuracy achieved with a daily model in tracking high pulse flows is particularly pronounced.

A methodology is described on page 132 of Chapter 6 and further explored in Chapter 8 for combining *SIM* and *SIMD* in modeling Senate Bill 3 environmental flow standards (EFS). Daily EFS targets computed in a daily *SIMD* simulation are summed to monthly volumes within *SIMD*. The resulting sequences of monthly target volumes from *SIMD* simulation results are inserted as target series *TS* records in the *SIM* input DSS file. As discussed on pages 249-250 of Chapter 8, the monthly summations of EFS instream flow targets computed by *SIMD* are replicated exactly in the monthly *SIM* simulation, but shortages in meeting the instream flow targets may vary greatly between the daily and monthly simulations. The strategy for combining daily and monthly models is valid for incorporating EFS set-asides in the WAMs and assessing effects on unappropriated stream flows. However, daily models should applied directly without conversion to monthly to accurately assess capabilities for supplying the EFS instream flow targets.

Relative Effects of Different *SIMD* Additions on Simulation Results

The comparative evaluation in Chapter 7 is based on a simplified example but does provide insight regarding the relative effects of the various components of the daily *SIMD* simulation model listed in Table 10.1. The discussion in Chapter 7 is illustrative of the following more general observations, which are also supported by research studies that developed and applied daily Brazos, Trinity, Neches, and Colorado WAMs [7, 22, 23, 24, 25].

The great variability of stream flow is the primary factor responsible for the differences between the monthly versus daily simulations. The plots of naturalized flow in Chapters 7, 8, and 9 illustrate the continuous variability and occasional extreme fluctuations that are characteristic of river flows throughout Texas and elsewhere. Modeling within-month stream flow variability is the most significant aspect of the daily simulation model. Developing daily pattern stream flow hydrographs is the most important aspect of converting from a monthly to daily WAM.

In a daily simulation, refilling reservoir storage and meeting water supply demands in each day depends on the volume of stream flow available in that day. A monthly simulation averages out stream flow availability over the month, generally resulting in more stream flow being available for filling reservoir storage and supplying diversion targets as illustrated by Figure 2.1 in Chapter 2, while correspondingly reducing the unappropriated flows leaving the river system at the outlet. Instream flow targets and shortages are significantly affected by stream flow variability. Environmental high flow pulse standards are completely defined by stream flow variability.

A monthly simulation is implicitly based on the premise that the effects of water rights propagate to the outlet of the river system within the month. Routing and forecasting may be relevant in a daily simulation. The effects of reservoir refilling and releases and water supply diversions and return flows during the current day may affect downstream river flows over a number of future days. With routing activated, forecasting is needed to protect downstream senior water rights and model reservoir flood control operations in which reservoir releases depend on flows at downstream gages. Forecasting serves no purpose without routing and should not be employed unless routing is employed.

Routing parameters are very approximate and routing and forecasting are complex. In general, the simulation results for the example in Chapter 7 vary relatively little as a function of routing and forecasting. Likewise, simulation studies performed with the daily Brazos, Trinity, Neches, and Colorado WAMs [7, 23, 24, 25] demonstrated that simulation results are not necessarily improved by routing and forecasting. Further studies are needed to explore the effects of routing on *SIMD* simulation results for various different river systems and modeling applications. However, routing and forecasting may not be warranted in some or perhaps many or most modeling situations.

Negative incremental naturalized stream flows are a significant issue in monthly *SIM* simulations and can have a much greater effect in a daily *SIMD* simulation. The term "*negative incremental flow*" refers to time periods (days or months) during which the naturalized flow at the downstream end of a river reach are smaller than the flow at the upstream end. Negative incremental flows may significantly affect the results of the water availability computations outlined in Table 3.1 on page 39. Interactions between negative incremental flow adjustments, routing, forecasting, and other flow adjustments are complex. The several alternative negative incremental flow adjustment options including the recommended standard options for monthly and daily simulations are explained in Chapter 3.

The daily *SIMD* is necessary for WRAP modeling of reservoir flood control operations. *SIMD* includes comprehensive capabilities for modeling the operations of single reservoirs or multiple-reservoir systems with releases controlled by a combination of dam outlet capacities and specified allowable non-damaging flow levels at any number of gaging stations located at downstream sites. In a monthly *SIM* or monthly *SIMD* simulation, outflow equals inflow with no flow attenuation (storage) whenever the reservoir is full to the top of conservation storage capacity. Flood control operations greatly affect reservoir storage contents and downstream river flows during high flow periods but generally only minimally during non-flood periods. Flood control operations can affect high flow pulse components of environmental flow standards and vice versa.

The array of options for determining monthly water supply diversion targets is maintained in *SIMD*. The default is to uniformly distribute the monthly target over the days of the month. Within-month non-uniform daily variations of water supply diversion targets can be modeled using options controlled by *DW* and *DO* records. Input data for these options are generally very approximate and/or difficult to obtain. These optional features are listed in the third column of Table 10.2 and are not employed in the examples presented in this report. These *DW* and *DO* record options were also not adopted in the daily Brazos, Trinity, Neches, and Colorado WAMs [7, 23, 24, 25].

WRAP capabilities for modeling Senate Bill 3 (SB3) environmental flow standards are described in Chapter 4 of the *Reference Manual* and Chapters 6 and 8 of this *Daily Manual*. SB3 environmental flow standards are composed of subsistence, base, and high pulse flow components. Environmental standard *ES* and hydrologic condition *HC* input records control simulation routines that are included in both the monthly *SIM* and daily *SIMD* and are described in Chapter 3 of the *Users Manual*. Pulse flow *PF* and pulse flow option *PO* records are applicable only in a daily *SIMD* simulation and are covered in Chapter 4 of the *Users Manual*. The determination of subsistence and base flow targets is affected by within-month stream flow variability. The determination of high pulse flow targets is totally controlled by within-month stream flow variability. Simulated shortages in meeting all components of instream flow targets are greatly affected by the choice of daily versus monthly modeling.

HEC-DSSVue and TABLES

As discussed in the preceding Chapter 9 and elsewhere in the WRAP manuals, *HEC-DSSVue* and *TABLES* each provide certain time series data management and analysis capabilities not provided by the other and both include some of the same statistical analysis methods. The *TABLES* time series, frequency, and reliability analysis routines are applicable for analyzing simulation results stored in either a monthly *SIM/SIMD* OUT or CRM output file, daily *SIMD* SUB output file, or DSS file. The annual flood frequency analysis routine in *TABLES* is applicable with a daily *SIMD* output AFF file. Other routines in *TABLES* are applicable only with monthly *SIM* input datasets and monthly simulation results.

WRAP applications of HEC-DSS and its user-interface program *HEC-DSSVue* are covered in detail in Chapter 6 of the *Users Manual* and discussed throughout the other WRAP manuals. *HEC-DSSVue* is documented in detail in its user's manual available at the HEC website along with the *HEC-DSSVue* software. The WRAP programs *SIM*, *SIMD*, *TABLES*, *HYD*, and *DAY* are linked during compilation with a HEC-DSS library of routines allowing them to read input data from DSS files and store simulation results as DSS files. *HEC-DSSVue* is used to organize, manage, manipulate, display, and analyze time series data in DSS files.

HEC-DSSVue functions the same with either monthly or daily time series datasets. Capabilities are provided for both (1) compiling daily flows along with monthly *SIM/SIMD* time series input data and (2) managing, organizing, displaying, and analyzing *SIM* or *SIMD* simulation results. *HEC-DSSVue* provides convenient and efficient tools for compiling, updating, and managing *DF* record daily flow input datasets. The comprehensive, flexible arrays of data management and analysis capabilities provided by *HEC-DSSVue* are particularly essential for large WRAP datasets such as daily *SIMD* simulation results.

The Hydrologic engineering has recently significantly updated HEC-DSS and *HEC-DSSVue*. The May 2022 sub-version of the new HEC-DSS Version 7 (DSS7) is embedded in the July 2022 WRAP programs. Preceding versions of WRAP incorporate HEC-DSS Version 6 (DSS6). The new 2021/2022 *HEC-DSSVue* Version 3 functions with either DSS6 or DSS7 files. The old *HEC-DSSVue* Version 2 reads and creates only DSS6 files.

Daily Flows Programs *DAY* and *DAYH*

The WRAP hydrology program *HYD* documented by the *Hydrology Manual* consists of a set of routines for compiling, synthesizing, and updating monthly times series of stream flows, reservoir evaporation rates, precipitation rates, and net evaporation-precipitation rates for monthly hydrology input datasets shared by *SIM* and *SIMD*. The WRAP programs *DAY* and *DAYH* facilitate compiling additional daily input data that is used only with *SIMD*.

Calibration of routing parameters is a primary purpose of *DAY* and *DAYH*. However, both programs also include other stream flow data compilation, manipulation, and analysis capabilities. *DAYH* is an older program which has been largely replaced by the more recently developed methods implemented in *DAY* for most typical applications of the daily WRAP. However, the alternative methods in *DAYH* may still be useful for certain applications and purposes.

Calibration routines in *DAYH* apply mathematical optimization procedures with alternative objective function options using entire upstream and downstream hydrographs. The calibration capabilities employed by *DAY* are based on statistical analyses of lag and attenuation metrics defined for observed flow changes. *DAYH* is applicable to both the Muskingum and lag/attenuation methods. *DAY* is applicable only to the lag/attenuation method. Both methodologies are based on analyzing daily streamflow hydrographs, which can be either observed flows or naturalized flows.

Routing techniques model the lag and attenuation effects of unsteady flow as stream flow fluctuations propagate downstream. Stream flow routing is addressed extensively in textbooks and the research literature, but from a very different perspective than the routing related methodologies in *SIMD*. Routing in the literature usually refers to routing of entire flood hydrographs. Routing in *SIMD* refers to the propagation of individual effects of each water right on downstream flows. *SIMD* routes incremental flow changes rather than total flow hydrographs. Unsteady flow hydraulics models such as the widely applied Hydrologic Engineering Center *HEC-RAS River Analysis System* require detailed river channel and overbank geometric data and calibrated energy head loss coefficients that are far outside of the scope of water availability modeling studies.

Studies noted in Chapter 4 [11, 15] explore observed stream flow characteristics from the perspective of developing routing methods and parameters for use in *SIMD*. Routing methods and routing parameter calibration are characterized by high random variability and inaccuracies. Relationships between stream flow variability at multiple sites on a river appear highly random and difficult to relate to variables within the *SIMD* simulation. Routing and associated parameter calibration methods are inherently very approximate. The statistically based *DAY* analysis methods provide capabilities for assessing the variability of lag and attenuation metrics.

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APPENDIX A
PROGRAM *DAILY FLOWS (DAY)*

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Tasks Performed by Program Daily Flows (DAY)

The WRAP program *Daily Flows* (executable file *DAY.exe*) provides a set of routines for compiling daily flow data, computing lag and attenuation metrics used to estimate values for routing parameters, disaggregating monthly flows to daily, and performing statistical analyses. The program reads input files of observed, naturalized, or simulated daily stream flows, performs statistical, lag/attenuation, and other analyses using these datasets, and creates output files containing datasets of daily stream flows and the results of the various computations. The program is also used to simply convert files of either daily or monthly flows between different formats.

DAY serves the purposes outlined in the following table. Each of the optional routines are activated by parameters JOB, FREQ, and REGCOR in job control *JC* record fields 7, 12, and 13.

Table 1
Tasks Performed by Program *Daily Flows* (*DAY*)

JOB	
1	Daily flows are simply read from a file and stored in another file.
2	Changes in daily flows are computed for all control points.
3	Lag and attenuation are computed for flow decreases for one stream reach.
4	Lag and attenuation are computed for flow increases for one stream reach.
5	Lag and attenuation are computed for flow decreases for multiple reaches.
6	Lag and attenuation are computed for flow increases for multiple reaches.
7	Flow decrease quantities are computed for all NCP control points.
8	Flow increase quantities are computed for all NCP control points.
9	Monthly flows are disaggregated to daily based on pattern daily flows.
10	Monthly flows are uniformly disaggregated to daily.
11	Monthly flows are converted between FLO and DSS file types and formats.
FREQ	Frequency analyses for daily flows (JOB options 1, 2, 3, 4, 5, 6, 7, or 8).
REGCOR	Regression and correlation analyses for daily quantities (JOB options 1-8).

DAY can be used to convert a dataset of daily flows from one file type and format to another (JOB option 1). The Hydrologic Engineering Center (HEC) Data Storage System (DSS) is the default *DAY* method for storing daily flow sequences, but flows can also be read from and written to files in the old DCF file format developed for the WRAP program *SIMD*. Flows can be stored in DCF files in either *DF* record or columnar formats. *DAY* can read daily flows from a DSS file or DCF input file and write the flows in a different format to either type of output file. DSS record pathnames may also be changed between a DSS input file and DSS output file. Unit conversions can be made using the multiplier factor XF entered on the *JC* record. Choices for input and output of daily flows are controlled by *JC* record parameters INF and OUTF. DSS record pathname options for DSS input and output files are provided by *DS* and *PN* input records.

Lag and attenuation analysis (JOB options 3-6) designed to support estimation of *SIMD* routing parameters is a primary motivation for program *Daily Flows*. The analysis is based on flow changes at the upstream and downstream ends of a river reach. The flow change at a site for each

day is computed as the daily flow for that day less the daily flow in the preceding day. Lag and attenuation quantities are computed based on the sequences of flow changes at upstream and downstream control points. Flow changes (JOB option 2) and lag and attenuation quantities (JOB options 7 and 8) can be recorded in DSS and DAY files as controlled by *JC* record entries for FCDSS and FCDA. The lag and attenuation computational procedure is described in Chapter 4.

Routines activated by parameters *FREQ* and *REGCOR* in job control *JC* record fields 12 and 13 perform several types of statistical analyses for daily flow data defined by JOB options 1 through 8. Frequency analyses are activated by the *JC* record parameter *FREQ*. Regression and correlation analyses are activated by *REGCOR*. Monthly flows are not included in the program *Daily Flows (DAY)* *FREQ* and *REGCOR* routines, but similar statistical analyses capabilities for monthly flows are provided by programs *HYD* and *TABLES*.

Frequency metrics include means, standard deviations, and quantities exceeded specified percentages of the time. Frequency tables may be developed for daily flows (*FREQ* option 1), lag and attenuation (*FREQ* option 2), and flow change quantities (*FREQ* options 3, 4, 5, 6, and 7).

Regression and correlation analyses are performed to relate flows at two sites (*REGCOR* option 1) and to relate lag and attenuation to flow (option 2). Trend analysis can also be performed by regressing flow or flow changes with time in days (options 3 and 4). Linear and power function regression coefficients and Spearman and standard linear correlation coefficients are computed.

The program deals primarily with sequences of daily flows. Sequences of monthly flows are read only for JOB options 9, 10, and 11. Monthly flows are written to an output file only for JOB option 11. Frequency, regression, and lag/attenuation analyses are applicable only to daily flows. Monthly flows may be disaggregated to daily using daily pattern hydrographs (JOB option 9) or a constant uniform distribution (JOB option 10). JOB option 11 simply reads monthly flows and then records the monthly flows in another file in a different format. Programs *SIM* and *HYD* also contain optional routines for changing file formats for monthly naturalized flow volumes.

JOB option 9 combines daily flow pattern hydrographs with *WRAP/WAM* monthly naturalized flows to develop daily naturalized flows. This same task is performed within the *SIMD* simulation. However, this optional *DAY* routine provides another convenient means to replace *SIMD* input datasets of daily flow pattern hydrographs consisting of observed or synthesized daily flow rates in cubic feet per second (cfs) with naturalized daily flow volumes in acre-feet.

JOB option 10 converts monthly flow volumes to daily volumes by dividing the monthly flow volumes by the number of days in the month. Monthly flows are uniformly disaggregated over the days of the months.

Job control *JC* record JOB option 11 converts sequences of monthly flow volumes in a *FLO* or *DSS* file from one alternative file type and format to another. Monthly flows are read from one file and written to another file. Programs *SIM* and *HYD* also contain routines for converting monthly naturalized flows between file formats.

Program DAY

Input and Output Files

Program *Daily Flows* (*DAY*) input and output files are listed below. The DIN input file is always required, and the DMS message file is always automatically created. The other files are used only if required by options selected on the DIN file input records.

DIN – input <i>JC</i> , <i>CN</i> , <i>MD</i> , <i>DS</i> , and <i>PN</i> records	filename: root.DIN
DCF – input file with daily flows	filename: root.DCF
DSS – input file in DSS binary format	filename: root.DSS
FLO – input of monthly flows	filename: root.FLO
DMS – message file	filename: root.DMS
DAY – output file with analysis results	filename: root.DAY
DCF – output file with daily flows	filename: root2.DCF or rootOUT.DCF
DSS – output file in DSS format	filename: root2.DSS or rootOUT.DSS
FLO – output file of monthly flows	filename: root2.FLO or rootOUT.FLO

DCF, DSS, and FLO files containing stream flow data serve as either input or output files. By default, the same filename root is assigned to all input and output files by the model user, and the program automatically adds OUT to the filename root of DCF, DSS, and FLO output files. Alternatively, the user can enter two filename roots with the second filename root assigned to only DCF, DSS, and FLO output files.

Program *Daily Flows* is a Fortran program which has been compiled as an executable file with the filename *DAY.exe*. Thus, program *Daily Flows* is also referred to as program *DAY*. The executable program can be executed either within the WRAP interface program WinWRAP or independently of WinWRAP. If executed within WinWRAP, the executable file must have the filename *DAY.exe*. Otherwise, the root of filename can be changed from *DAY* to essentially anything. The program *Daily Flows* (or *DAY*) input and output file extensions listed above are always required. By default, a single filename root entry through WinWRAP is attached to all files, but WinWRAP also allows entry of a second filename root for DCF, DSS, and FLO output files.

Control Points

The input flow sequences and quantities computed therefrom are located at control points and are labeled by control point identifiers. With the exceptions of lag/attenuation that combines upstream and downstream flows and REGCOR option 1, the computations for flows at each control point are independent of flows at all other control points. Control point identifiers have the same format used in all the WRAP programs. Up to ten control point identifiers can be listed on a single *CP* record. Any number of *CP* records can be used if the number of control points exceeds ten. There is no limit on the total number of control points (NCP). With the exception of the JOB option 11 automated control point count, NCP must be specified in *JC* record field 2.

Alternative mechanisms for specifying control point identifiers are as follows.

- With daily flows read from a DSS file (INF option 1), all relevant control points must be listed on *CP* records.

- If daily flows are read from a DCF file (INF option 2), control points may be selected by listing them on *CP* records, but if no *CP* record is provided, all control point identifiers are read from the *DF* records along with reading the daily flows.
- For INF option 3, control point identifiers are always read from the first row of the DCF file data along with reading the daily flows from the DCF file.
- With JOB option 9 activated, monthly flows at specified control points are disaggregated to daily flows at the same control points based on daily pattern hydrographs at the same or different control points. Control point identifiers are listed on *CP* records if the daily flow pattern hydrographs are located at the same control points as the monthly flows. *MD* records are used to specify monthly and daily flow control points if the daily flow pattern hydrographs are located at different control points than the monthly flows.
- With JOB option 11 activated, the control point locations of the monthly flows can be listed on *CP* records. Alternatively, control point identifiers can be read from the FLO file along with the monthly flows. With monthly flows read from a DSS file (MFIN option 1), all relevant control points must be listed on *CP* records.

Lag and attenuation are computed for flow change events in a river reach defined by upstream and downstream control points. Normally, a lag and attenuation analysis will consider just two control points which define the upstream and downstream ends of the stream reach. However, with JOB options 3 and 4, NCP may be greater than two to allow consideration of upstream flows on multiple tributaries. The last control point represents the downstream end of the reach. The daily flows at all of the other control points are summed to obtain the total daily flows at the upstream end of the reach. The summation of flows each day at all upstream control points is assigned the identifier SUMUP. The lag and attenuation computations consider only two sequences of daily flows, upstream total flows and downstream flows. However, lag and attenuation may be computed for any number of reaches using JOB options 5 and 6.

Lag and Attenuation Analyses

The purpose of the lag and attenuation routine in *DAY* is to provide a basis for estimating values for the lag and attenuation routing parameters LAG, ATT, LAGF, and ATTF employed in the *SIMD* simulation model. The lag and attenuation computational methodology and associated parameter calibration strategy are explained in Chapter 4.

Program *DAY* does not directly calibrate optimal values for the routing parameters but rather provides information to be applied with judgment to estimate values for the parameters. The *DAY* lag and attenuation analysis computations are performed for a river reach based on daily flow increases or decreases at the upstream and downstream ends of the reach. Lag and attenuation, as defined in Chapter 4, are computed for flow change events which may have durations of one day or multiple days. The flow change at a control point for each day is computed as the daily flow that day less the daily flow in the preceding day. The analysis can be performed for either flow decreases or flow increases. With *JC* record JOB option 3, flow changes are defined as decreases in flow. Conversely, with JOB option 4, only flow increases are employed in the computations. If flow changes are defined in terms of decreasing flow, the absolute value of the flow change is employed in the computations, meaning flow changes are always defined as positive numbers.

Program DAY

Observed daily flows at two gaging stations over a long period-of-record will contain numerous flow change events. The optional lag parameter *LP* record provides a set of additional criteria for selecting which of the flow change events are adopted for compiling a series of lag and attenuation quantities. These criteria are explained in Chapter 4.

The alternative strategies for employing more than two control points to specify flows at the upstream and downstream ends of a river reach is the only difference between JOB options 3 and 4 and JOB options 5 and 6. With only two control points on the *CP* record, there is no difference. With JOB options 3 and 4, only one reach is considered. With JOB options 3 and 4, if the number of control points on *CP* records is greater than two, the last control point represents the downstream end of the reach. The daily flows at all of the others are summed to obtain the total daily flows at the upstream end of the reach.

With JOB options 5 and 6, control points on *CP* records may define the upstream and downstream ends of any number of reaches. With JOB options 5 and 6 combined with multiple control points on *CP* records (*NCP* greater than 2), the first lag/attenuation analysis uses the first control point listed on the *CP* record as the upstream end of the reach, and the second control point is the downstream end. The second lag/attenuation analysis employs the second control point listed on the *CP* record as the upstream end of the reach, and the third control point is the downstream end. For the third lag/attenuation analysis, the third and fourth control points are the upstream and downstream ends of the reach. Next, the fourth and fifth control points are paired and so forth.

Computed lags in units of days are zero or positive numbers. Computed attenuations are positive numbers that are always greater than zero. Every computed lag has a corresponding computed attenuation. The lags and attenuations are assigned to the day of the flow change event that has the peak flow change at the upstream end of the river reach. The days with an assigned lag and attenuation are a subset of all of the days of the period-of-analysis defined in *JC* record fields 11-13. The frequency analysis and regression and correlation analysis routines are applied to all computed lags and attenuations, but exclude all days not assigned lag/attenuation. Lag may include zero as well as positive numbers. The attenuations are all positive numbers, with no zeros.

At the beginning of the computations, a lag value of -9.0 is assigned to all days of the period-of-analysis defined in *JC* record fields 3-6. A value of 0.0 is assigned for attenuation for each of the total number of days in the period-of-analysis. The -9.0s and 0.0s are replaced as computed lags and attenuations are assigned to the appropriate upstream peak flow days. The final results of the lag and attenuation computation routine is a compilation of lag and attenuation values. The *LP* record criteria control removal of lag and attenuation values from the compilation. A -99.0 and 0.0 are assigned to the lag and attenuation for the days in which the computed lag and attenuation are removed. Several of the output options specify tabulations for all days of the period-of-analysis. Lags are shown as -9.0 and -99.0 for the days without adopted computed lags. The parameter *L99* in *LP* record field 2 provides the option of converts the -9.0s and -99.0s to 0.0s.

Output options for the quantities computed in the lag and attenuation analysis are selected using *JC* record switch parameters *FCDSS* and *FCDAY*. The most detailed tabulation of computation results is created by *FCDAY* option 4. Frequency analyses can be applied to the series of lag and attenuation values to support selection of the routing parameters employed in a *SIMD* simulation. Regression and correlation analyses relate lag and attenuation to stream flow.

Frequency Analyses

Frequency analysis tables are created in the DAY file in a standard columnar format that includes the sample size (number of days in the data series), mean, standard deviation, and the quantities exceeded specified percentages of the time. For all FREQ options except option 2 (lag and attenuation), a column of metrics is provided for each control point. A single table includes all of the control points. For option 2, a separate frequency table is provided for each control point, with each table containing separate columns of metrics for lag and attenuation.

Exceedance frequencies or probabilities are based on the following relative frequency formula, where *m* denotes rank and *N* is the sample size (number of days included in the analysis).

$$\text{exceedance Frequency} = \frac{m}{N} (100\%)$$

Frequency metric tables may be developed for the following daily data series as selected by the parameter FREQ in *JC* record field 8.

- FREQ option 1: The frequency metrics for the period-of-analysis daily flows at any number of control points are computed. The resulting table includes a column of frequency analysis results for the daily flows at each control point. (JOB options 1-8)
- FREQ option 2: The computed lag and attenuation values. Two sets of metrics are provided, one for lag in days and the other for attenuation. (JOB options 3, 4, 5, 6, 7, 8)
- FREQ option 3: Flow increases (JOB=3,5) or decreases (JOB=4,6) without *LP* record constraints for at each of the NCP control points. The sample size is the number of days with either flow increases (JOB=3,5) or flow decreases (JOB=4,6).
- FREQ option 4: The frequency analysis table includes a column of results for the flow changes at each of the NCP control points. Flow changes for all days are included in the frequency analyses, including zero, positive, and negative quantities. (JOB=2)
- FREQ option 5: The daily flow in the peak day for either each flow decrease event (JOB=3) or flow increase event (JOB=4). The sample size is the number of flow change events. The random variable is the maximum daily flow change for each event.
- FREQ option 6: The event-total summation of daily flow changes for either each flow decrease event (JOB=3,5,7) or flow increase event (JOB=4,6,8). The random variable is the sum of the flow change in all days of each event. The sample size is the number of flow change events.
- FREQ option 7: The duration in days of flow change events for either flow decreases (JOB=3,5,7) or flow increases (JOB=4,6,8). The duration is the integer number of days of each flow change event. The events are either flow increases or decreases as defined by JOB options 3 and 4 entered in *JC* record field 2.

Regression and Correlation Analyses

The regression and correlation analyses activated by REGCOR in *JC* record field 9 can be employed to develop relationships for the following variables.

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- Option 1: Regression and correlation of stream flows at two different control points.
- Option 2: Lag (Y) versus flow (X) and attenuation (Y) versus flow (X).
- Option 3: Trend analysis of flow (Y) as a function of time in days (X).
- Option 4: Trend analysis of flow changes (Y) as a function of time in days (X).

A summary table of regression and correlation coefficients is created for each control point. The table includes regression coefficients for standard linear regression, linear regression with the Y-intercept fixed at zero, and power function regression. The table also includes standard linear correlation coefficients, Spearman rank linear correlation coefficients, and coefficients of determination. The correlation coefficients provide a relative measure of the closeness-of-fit of the three alternative regression models. An optional auxiliary tabulation of the data series and ranks can also be created.

Linear regression is applied both with and without constraining the Y-intercept coefficient to be zero.

$$Y = a + bX \quad \text{and} \quad Y = bX$$

Standard least-squares linear regression methods outlined in statistics and numerical methods textbooks are employed in program *Daily Flows*.

$$E(Y | X) = a + bX$$
$$b = \frac{n \sum x_i y_i - (\sum x_i)(\sum y_i)}{n \sum x_i^2 - (\sum x_i)^2}$$
$$a = \bar{y} - b \bar{x}$$

$E(Y | X)$ denotes the conditional expectation of Y given X, and \bar{y} \bar{x} are the means of Y and X. The coefficients a and b represent the y-intercept and slope of a straight line plot. With the option of fixing the Y-intercept (coefficient a) at zero, the coefficient b is computed as follows.

$$b = \frac{\sum x_i y_i}{\sum x_i^2}$$

Nonlinear regression using the power equation is performed using the standard method of applying linear regression to the logarithms of the X and Y data and transforming the results to obtain the coefficients **a** and **b**.

$$Y = aX^b$$

Linear regression is applied to the logarithm of Y regressed with the logarithm of X, with the resulting y-intercept and slope of a straight line being represented by log a and b, respectively. The coefficients **a** and **b** in the power regression equation are related to the coefficients a and b computed by linear regression of log x and log y as follows.

$$b = b$$
$$a = 10^a$$

The standard linear correlation coefficient R is computed in *DAY* for the three alternative regression models. The Spearman rank linear correlation coefficient is also computed. The following standard linear correlation coefficient equation is employed.

$$R = \frac{n \sum x_i y_i - (\sum x_i)(\sum y_i)}{\sqrt{n \sum x_i^2 - (\sum x_i)^2} \sqrt{n \sum y_i^2 - (\sum y_i)^2}}$$

The Spearman rank correlation coefficient does not depend upon the actual values of X and Y 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 the linear correlation equation. 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.

Values of the correlation coefficient can range between -1.0 and 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 linear correlation coefficient is an index of the goodness-of-fit of the regression relationships. When employing power regression, the linear correlation coefficient is an index of the linear correlation between the previously noted logarithmic transformed variables.

The coefficient of determination R^2 is also included in the set of *DAY* regression and correlation metrics. R^2 is computed by a standard equation that incorporates the regression coefficients. For standard linear regression, the coefficient of determination R^2 is the correlation coefficient R squared, and R^2 is always a positive number between zero and one. However, with the Y -intercept fixed at zero, R^2 is not necessarily R squared, and R^2 may be negative.

Disaggregation of Monthly Flows to Daily (JOB Option 9)

The WRAP simulation model *SIMD* disaggregates monthly naturalized flows to daily flows while preserving the monthly volumes. Several optional flow disaggregation methods are included in *SIMD*, with the recommended standard being to distribute the monthly flow volume over the month in proportion to daily flows of a daily flow pattern hydrograph. This methodology is also included in *DAY*. Although disaggregation computations are performed within *SIMD*, the *DAY* disaggregation routine provides a convenient means to replace datasets of daily flow pattern hydrographs consisting of observed or synthesized daily flow rates in cubic feet per second (cfs) with actual naturalized daily flow volumes in acre-feet.

Disaggregation computations are performed by *DAY* to compute daily naturalized flow F_{DN} , typically in acre-feet/day, for each day of each month of the period-of-analysis as follows.

1. The monthly naturalized flow volumes M_{FN} (typically in acre-feet) and the daily flows F_{DP} (in cfs or ac-ft) comprising the daily flow pattern hydrograph are read from the input file.
2. The daily flows F_{DP} are summed to obtain a monthly total summation S_D .

Program DAY

3. The daily naturalized flows F_{DN} for each day of the month are computed as follows. If M_{FN} is zero, the F_{DN} is zero for all days of the month. If the summation S_D is zero but M_{FN} is not zero, the uniform F_{DN} for each day is M_{FN} divided by the number of days in the month. Otherwise, $F_{DN} = M_{FN} \times (F_{DP}/S_D)$

JOB option 9 in *JC* record field 7 activates the disaggregation routine. The parameter MDD in *JC* record field 14 controls whether the computed F_{DN} are treated as "flows" or "flow changes". With MDD option 1, the final daily flows resulting from the disaggregation computations are the flows output with OUTF options and analyzed with *FREQ* and *REGCOR* options. With MDD option 2, the final computed daily flows are the "flow changes" output by *FCDAY* option 1 and otherwise analyzed, and the original pattern hydrograph is stored as the "flows".

Monthly flows are read from either the DSS input file (*MFIN* option 1) or a FLO input file (*MFIN* options 2 or 3). Daily flow sequences (pattern hydrographs) can be read with any of the *INF* options, with the default being the DSS file.

Monthly flows are disaggregated to daily flows at the same control point based on pattern daily flows at either the same or a different control point. The total number of control points *NCP* for flow disaggregation includes all of those listed on *CP* records plus those additional control points listed on *MD* records. Any number of control points can be specified on *CP* and/or *MD* records. *MD* records are required only if the monthly/daily flows are at different control points than the daily pattern hydrograph flows. The control points listed on *CP* records are employed the same for monthly flows, disaggregated daily flows, and pattern daily flows.

Converting between FLO and DSS File Formats for Monthly Flows (JOB Option 11)

Sequences of monthly naturalized flow volumes are stored either as *IN* records in a FLO file or as DSS records in a DSS file. Programs *SIM* and *SIMD* read the monthly naturalized flow volumes as simulation input. Programs *HYD*, *SIM*, and *SIMD* include options for converting flows between FLO and DSS files. Likewise, *DAY* JOB option 10 allows file conversions.

Selection parameters *MFIN* and *MFOUT* in *JC* record fields 15 and 16 specify the input and output file type and format for monthly flows. Monthly flow sequences can be read from a DSS or FLO input file and then written to either a DSS or FLO output file in specified formats. The term *OUT* is automatically appended to the filename root to differentiate output files from input files. Thus, flows can be converted from one file type and format to another. The monthly flows can also be multiplied by *XF* from *JC* record field 17 for unit conversions or other purposes.

The total number of control points *NCP* must be specified in *JC* record field 2 in all cases except the following. *NCP* is not used or required only if JOB option 10 is activated, either *MFIN* option 2 or 3 is activated, and no *CP* record is provided. In this case, the number of control points with monthly flows is counted from the FLO file, and all control points in the FLO file are included. One or more *CP* records and a non-zero *NCP* entered in *JC* record field are required if the monthly flows are read from a DSS file (*MFIN* option 1). *CP* records can also be employed to select a subset of control points rather than all the control points in the FLO file (*MFIN* options 2 and 3). Without a *CP* record, with *MFIN* option 2 or 3 selected, all of the control points included in the FLO file are adopted.

JC Record – Job Control

field	columns	variable	format	value	description
1	1-2	CD	A2	JC	Record identifier.
2	3-8	NCP	I6	+	Number of control points.
<u>Time Span</u>					
3	11-12	BEGMT	I4	+	Beginning month (1, 2, 3, ... , 12). Default = 1
4	13-16	BEGYR	I4	+	Beginning year (required).
5	19-20	ENDMT	I4	+	Ending month (1, 2, 3, ... , 12). Default = 12
6	21-24	ENDYR	I4	+	Ending year (required).
<u>Type of Job</u>					
7	28	JOB	I4	blank,0,1	Flows are read from a file and stored in another file.
				2	Computation of flow changes for all control points.
				3	Lag/attenuation, flow decreases, one stream reach.
				4	Lag/attenuation, flow increases, one stream reach.
				5	Lag/attenuation, flow decreases, multiple reaches.
				6	Lag/attenuation, flow increases, multiple reaches.
				7	Flow decrease quantities for all NCP control points.
				8	Flow increase quantities for all NCP control points.
				9	Pattern disaggregation of monthly flows to daily.
				10	Uniform disaggregation of monthly flows to daily.
				11	Transfer of monthly flows between file formats.
<u>Input File for Daily Flows (JOB Options 1-9)</u>					
8	32	INF	I4	blank,0,1	DSS file.
				2	DCF file in standard DF record format.
				3	DCF file with flows in columns.
<u>Output File for Daily Flows (JOB Options 1-9)</u>					
9	36	OUTF	I4	1	DSS file.
				2	DCF file in standard DF record format.
				3	DCF file with flows in columns.
<u>Flow Change Quantities in DSS Output File</u>					
10	40	FCDSS	I4	1	Flow changes for NCP control points to DSS file.
				2, -2	Flow, lag, and attenuation recorded in DSS file.
<u>DAY File Options for Flow Change Quantities</u>					
11	44	FCDAY	I4	1	Flow changes for NCP control points to DAY file.
				2, -2	Flow, lag, and attenuation to DAY file.
				3, -3	Flow change event quantities for all control points.
				4, -4	All flow change analysis quantities to DAY file.
<u>Frequency Analysis Results in DAY File</u>					
12	48	FREQ	I4	1	Daily flows at all control points.
				2	Lag and attenuation.
				3	Flow increases only or flow decreases only.
				4	All flow changes, positive, negative, and zero.
				5	Daily flow changes in the event peak days.
				6	Summation of flow change in all days of events.
				7	Duration in days of flow change events.

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JC Record – Job Control (Continued)

field	columns	variable	format	value	description
13	52	REGCOR	I4	1 2 3 4	<u>Regression and Correlation Results in DAY File</u> Flow at 2 nd control point versus flow at 1 st control pt. Lag in days versus flow. Attenuation versus flow. Trend analysis of flow versus time in days. Trend analysis of unadjusted flow change vs days.
14	56	MDD	I4	blank,0,1 2	<u>Disaggregation of Monthly Flows to Daily (JOB=9)</u> Daily flows are stored as daily flows. Daily flows are stored as daily flow changes.
15	60	MFIN	I4	blank,0,1 2 3	<u>Input File for Monthly Flows (JOB = 9 or 10)</u> Monthly flows are read from DSS file. Monthly flows are read from FLO file by control pt. Monthly flows are read from FLO file by year.
16	64	MFOUT	I4	blank,0,1 2 3	<u>Output File for Monthly Flows (JOB = 10)</u> Monthly flows are written to DSS file. Monthly flows are written to FLO file by control pt. Monthly flows are written to FLO file by year.
17	65-72	XF	F8.0	+	<u>Stream Flow Multiplier Factor (JOB = 1-10)</u> Unit conversion or other factor. Default = 1.0

Explanation of JC Record Fields

Field 2: DAY operations are performed for the number of control points NCP specified in JC record field 2. Lag and attenuation computations are performed for river reaches defined by flows at the upstream and downstream control points. The other DAY operations are performed for any number of flow sequences represented by their control points, with each control point (flow sequence) treated independently of the others. Additional control points can be listed on MD records for monthly-to-daily flow disaggregation (JOB option 9).

With the default INF option 1 (JC record field 8), NCP control point identifiers are read from the DSS file for control points listed on CP records in the DIN file. CP records are required if INF=1. With INF option 2, if CP records are not provided, the control point identifiers are read from the DF records in the DCF file. If CP records are used, flows are read from the DCF file for the NCP control points listed on the CP records. With INF option 3, all of the NCP control point identifiers are read from the top of the columns in the DCF file. CP records are not allowed.

Fields 3-6: The period covered by the flow data sequences is defined by fields 3-6. The beginning and ending years are required. The beginning and ending months default (blank fields 3 and 5) to January and December. All analyses extend from the first day of the first month of the first year through the last day of the last month of the last year.

Field 7: JOB specifies the type of job operations to be performed. The results of the job option operations can be recorded in DAY, DSS, and DCF output files. Statistical metrics for the data

series created by the various JOB options can be computed by routines activated by *FREQ* and *REGCOR* in *JC* record fields 12 and 13.

JOB option 1 consists of reading daily flows in a specified format (*INF* = 1, 2, or 3) and converting the data to another format (*OUTF* = 1, 2, or 3). The data may be multiplied by *XF* from field 14.

JOB option 2 specifies that daily changes in flow at each of the NCP control points be computed. The flow changes are unadjusted and include zeros and both positive and negative values.

JOB options 3, 4, 5, and 6 consist of computing flow changes and associated series of values for lag and attenuation. Options 3 and 5 define flow changes as decreases. Options 4 and 6 define flow changes as increases. Options 3 through 6 all include computation of lags and attenuations.

JOB option 3 results in a flow change series consisting of the absolute value of flow decreases. Zeros are assigned to all days in which flow decreases do not occur. Only one river reach, typically defined by only two control points, is considered with JOB options 3 and 4. If more than two control points are listed on *CP* records, the last control point listed represents the downstream end of the river reach. The upstream flows are the summation of flows at all of the other control points.

JOB option 4 results in a flow change series consisting of only flow increases. Zeros are assigned to all days in which flow increases do not occur. JOB options 3 and 4 deal with one reach defined by upstream and downstream flows, with multiple control points employed as noted above.

JOB options 3 and 5 result in a flow change series consisting of the absolute value of flow decreases. Zeros are assigned to all days in which flow decreases do not occur. Whereas option 3 deals with only one reach, option 5 allows any number of reaches. For JOB option 5, with multiple control points listed on *CP* records, the first and second, second and third, third and fourth, and so forth control points are paired to represent the upstream and downstream ends of different reaches. With only two control points listed on a *CP* record, JOB options 3 and 5 are identical.

JOB options 4 and 6 results in a flow change series consisting of only flow increases. Whereas, option 3 and 4 computations are limited to a single reach, the option 5 and 6 computations can be applied to any number of reaches. Options 3, 4, 5, and 6 all compute lag and attenuation.

JOB options 7 and 8 compute flow changes in the same manner as options 5 and 6 but do not include computation of lag and attenuation.

JOB option 9 combines daily flow hydrographs with monthly naturalized flows to develop daily naturalized flows. Options for managing the flow data associated with JOB option 9 are specified by *MDD* and *MFIN* in *JC* record fields 14 and 15.

JOB option 10 disaggregates monthly flow volumes to daily volumes by dividing the monthly flow volumes by the number of days in each month. Monthly flows are uniformly distributed over the days of the months.

JOB option 11 simply transfers monthly flows from one file to another as specified by *MFIN* and *MFOUT* in *JC* record fields 15 and 16. Monthly flows are read from either a *FLO* or *DSS* file and written to either a *FLO* or *DSS* file. *FLO* files can be organized in two alternative formats, *IN* records or columns.

Field 8: Daily flow sequences from either a *DSS* or *DCF* input file are required in executing *DAY*. The *DSS* input file option is the default. The flows in a *DCF* file can be in either the standard *DF* record or columnar formats employed by the *WRAP* programs *SIMD* and *DAY*.

Program DAY

Field 9: Daily flows can be recorded in either a DSS or DCF output file. Flows can be recorded in a DCF file in either the *DF* record or columnar formats employed by *SIMD* and *DAY*.

Fields 10 and 11: The flow change for each day is computed as the flow for that day less the flow in the preceding day. Lag and attenuation quantities are computed based on the sequences of flow changes at upstream and downstream ends of a stream reach. Flow changes and lag and attenuation quantities can be recorded in DSS and DAY files. DSS pathnames follow the standard conventions defined by either defaults or *DS* records. If lag and attenuation metrics are specified for output (FCDSS=2 or FCDAY=2, 4), JOB option 3, 4, 5, or 6 must be selected in field 3. If FCDAY = 3 JOB must be 3, 4, 5, 6, 7, or 8. If FCDAY or FCDSS = 1, JOB must be 2, 3, 4, 5, 6, 7, or 8.

FCDSS option 1 and FCDAY option 1 store flow changes at the NCP control points in the DSS or DAY file. The flow changes may be zero, negative, and positive numbers.

FCDSS option 2 stores the daily total flow, lag, and attenuation for all days in the DSS file. The lag computations include assigning -9.0 initially to indicate no lag and -99.0 to indicate exclusions due to LP record criterion. A -2 entered for FCDSS changes the -9.0s and -99.0s to zero.

The FCDAY options result in quantities being tabulated as columns in the DAY file. Entering 2, 3, or 4 for FCDAY results in tabulations for all days including days with no flow change. FCDAY of -2, -3, or -4 employs the same table format but includes only days with non-zero flow change.

FCDAY option 3 outputs the flow change event quantities for all control points but does not include lag and attenuation. Flow changes are stored for all days and can be zero for many days.

FCDAY option 4 creates a detailed table for each control point containing essentially all quantities computed during the lag and attenuation analysis computations. FCDAY options 1, 2, and 3 include only selected variables in the tables created in the DAY file. Option 4 provides the most complete set of quantities and largest tables.

Field 12: Frequency metrics recorded in the DAY file include the number of days in the data series, mean, standard deviation, and the quantities exceeded specified percentages of the time. Exceedance frequencies or probabilities (P) are based on relative frequency: $P = (m/N)100\%$, where m denotes rank and N is the number of days of data. Frequency tables are developed for the following daily data series by selecting FREQ options in *JC* record field 12.

FREQ option 1 is for daily flows at the NCP control points. Works with any of the JOB options.

FREQ option 2 is for the lag and attenuation series computed in the JOB option 3, 4, 5, or 6 procedures. Frequency statistics are computed separately for lag and attenuation.

FREQ option 3 is for either flow decreases (JOB = 3, 5, or 7) or flow creases (JOB = 4, 6, or 8) at all of the NCP control points.

FREQ option 4 is for all changes in daily flows at all of the NCP control points for all days and include zero, positive, and negative quantities. Works with any JOB option.

FREQ option 5 is for the daily flow in the peak day for JOB 3, 4, 5, or 6 flow changes at the NCP control points.

FREQ option 6 is for event-total summations of daily flow changes for the peak day for JOB 3, 4, 5, 6, 7, or 8 flow changes at the NCP control points.

FREQ option 7 is for the duration in days for the JOB 3, 4, 5, 6, 7, or 8 flow change events.

Field 13: Linear and power function regression coefficients and Spearman and standard linear correlation coefficients are computed. The following analyses are performed.

REGCOR option 1: Regression and correlation of stream flows at two different control points.

REGCOR Option 2: Lag versus flow and attenuation versus flow regression and correlation.

REGCOR Option 3: Trend analysis of flow as a function of time in days.

REGCOR Option 4: Trend analysis of flow changes as a function of time in days.

With a 1, 2, 3, or 4 in *JC* record field 13, a summary table of computed statistics and coefficients is created in the DAY file for each of the NCP control points (REGCOR = 3 or 4) or NCP-1 pairs of control points (REGCOR = 1 or 2). With -1, -2, -3, or -4 entered for REGCOR, a complete tabulation of the variables and their ranks is included in the DAY file as well as the summary table of statistics and coefficients.

For REGCOR option 1, the analyses are repeated for the first NCP-1 control points listed on the *CP* records. For the first regression/correlation analysis, X is flow at the first control point and Y is flow at the second control point. For the second regression/correlation analysis, X is flow at the second control point and Y is flow at the third control point. The next analysis is for flows at the 4th and 5th control points listed on the *CP* record, and so forth. For REGCOR options 3 and 4, the trend analyses are repeated for all of NCP control points listed on the *CP* records. With JOB option 3 or 4 activated, the REGCOR option 2 analyses of lag and attenuation are limited to one control point. Otherwise, the REGCOR option 2 analyses of lag and attenuation are repeated for the first NCP-1 control points listed on *CP* records.

Field 14: JOB option 9 (field 7) activates a routine that disaggregates monthly flows to daily. The disaggregation computations are the same with either MDD option 1 or 2 selected in field 14, but the resulting flows are stored and output differently. With the default MDD option 1, the final daily flows resulting from the disaggregation computations are the flows output with OUTF options 1, 2, and 3. With MDD option 2, the final computed daily flows are the "flow changes" output by FCDAY option 1, and the original daily pattern hydrographs are treated as the daily "flows".

Field 15: JOB options 9 and 10 (*JC* record field 7) require reading monthly flows from either a DSS file or FLO file as specified by MFIN in field 15. With the default MFIN option 1, monthly flows are read from the DSS file. With options 2 and 3, monthly flows are read from a FLO file.

The FLO file read by DAY has the same format as the FLO file read by *SIM* and *SIMD*. MFIN options 2 and 3 correspond to INEV options 2 and 1 entered in *JO* record field 2 for the program *SIM*. With MFILE option 2 (or INEV option 2), the monthly flows are grouped by control points. With MFILE option 3 (INEV option 1), the monthly flows are grouped by years.

Field 16: With JOB option 10 (*JC* field 7), monthly flows are read from the input file specified by MFIN (field 15) and written to the file specified by MFOUT (field 16). JOB option 10 is the only JOB option for which MFOUT (field 16) is relevant.

Field 17: The daily or monthly flows are multiplied by XF immediately after they are read from the input file. XF has a default (blank field 17) of 1.0. XF is intended for use primarily for unit conversions but is simply a multiplier factor that can be used for other purposes as well.

Program DAY

LP Record – Optional Lag Parameters

field	columns	variable	format	value	description
1	1-2	CD	A2	LP	Record identifier.
2	7-8	LF9	I6	Blank,0 -1.0	Lag values of -9.0 and -99.0 flag days with no lag. The -9.0 and -99.0 lag flags are replaced with zeros.
3	9-16	LP(1)	F8.0	blank,0 +	<u>Minimum Lag Time</u> Default minimum lag time is 0.00 day. Minimum lag time in days.
4	17-24	LP(2)	F8.0	blank,0 ≤ -1.0 +	<u>Same-Day Downstream Flow Change Upper Limit</u> Same-day downstream criterion is not applied. There can be no positive flow change downstream. Upper limit as a fraction of upstream flow change.
5	25-32	LP(3)	F8.0	+	<u>Lower and Upper Limits on Upstream Flow Changes</u> Minimum limit on change in flow. Default = 0.0
6	33-40	LP(4)	F8.0	+	Maximum limit on change in flow. Default no limit.
7	41-48	LP(5)	F8.0	+	<u>Lower and Upper Limits on Downstream Changes</u> Minimum limit on change in flow. Default = 0.0
8	49-56	LP(6)	F8.0	+	Maximum limit on change in flow. Default no limit.
9	57-64	LP(7)	F8.0	+	<u>Lower and Upper Limits on Upstream Flows</u> Minimum limit on total flow. Default = 0.0
10	65-72	LP(8)	F8.0	+	Maximum limit on total flow. Default no limit.
11	73-80	LP(9)	F8.0	+	<u>Lower and Upper Limits on Downstream Flows</u> Minimum limit on total flow. Default = 0.0
12	81-88	LP(10)	F8.0	+	Maximum limit on total flow. Default no limit.

A lag and attenuation analysis is performed if FCDSS option 2, FCDAAY option 2, FREQ option 2, and/or REGCOR option 2 is specified in *JC* record fields 6, 7, 8, and 9. Either JOB options 3 or 4 must be specified. Lag and attenuation computations are performed for only decreases in flow (JOB=3) or increases in flow (JOB=4). The *LP* record is optional. If a lag and attenuation analysis is performed without a *LP* record, defaults are adopted for all of the parameters on the *LP* record.

The *LP* record provides criteria applied in the selection of flow change FC events to be employed in the computation of lag and attenuation. The criterion of defining flow changes as either flow decreases (JOB=3) or flow increases (JOB=4) is controlled by JOB on the *JC* record. Other optional criteria for defining flow change events are provided by the *LP* parameters on the *LP* record. The *LP* record parameters do not result in adding more FC events but rather may eliminate some of the FC events from inclusion in the lag and attenuation analysis. A particular flow change FC event is included in the computed values of lag and attenuation only if all of *LP* record criteria are satisfied for that flow change event.

Explanation of LP Record Fields

Field 2: The parameter LF9 has no effect on computations but does affect the presentation of lag computation results. A lag value of -9.0 and attenuation value of 0.0 are assigned to all days of the period-of-analysis at the beginning of the computations. The final product of the lag and attenuation computation routine is a compilation of lags and attenuations. The LP record criteria specify removal of lag and attenuation values from the compilation. A -99.0 and 0.0 are assigned to the lag and attenuation for the days in which the computed lag and attenuation are removed. Several of the output options specify tabulations for all days of the period-of-analysis. Lags are shown as -9.0 and -99.0 for the days without adopted computed lags. The -9.0 s and -99.0 s can be converted to zeros by entering -1 or any negative integer for LF9 in LP record field 2.

Field 3: The lag for a flow change FC event is the time in days T_P between the instantaneous flow peaks Q_P at the upstream and downstream ends of the reach. If LP(1) in LP record field 2 is zero, the next downstream event in time is selected. Otherwise, the next downstream flow change event with a T_P at least LP(1) days later than the upstream T_P is paired with the upstream event.

Field 4: For JOB=3 decreasing FC, a negative entry for LP(2) in LP record field 4 means that a upstream FC event is not included in the computations if there is a non-zero decrease in flow at the downstream site in the same day as the upstream T_P . Likewise for JOB=4 and negative LP(2), an event is excluded if there is a flow increase at the downstream end of the reach in the same day as the upstream T_P . With a positive LP(2), selection of an event requires that the downstream peak day flow change FC not exceed the upstream peak day FC in that same day by more than $FC \times LP(2)$. For example, with LP(2)=0.10, and an increasing flow event will not be included in the compilation if the downstream flow increase during the upstream peak flow day exceeds 10% of the upstream flow increase during that same day.

Fields 5-8: Upper and lower limits at the upstream and downstream ends of the stream reach can be optionally placed on the daily flow changes adopted for the analysis. A particular upstream FC event will not be included in the lag and attenuation compilation if the limits for either the upstream FC or its corresponding downstream FC are violated during the peak flow day of the FC event. Lags and attenuations computed from flow change events with peak day flow changes falling outside the specified limits are removed from the final compilation.

Fields 9-12: Upper and lower limits can be optionally placed on the daily flows at the upstream and downstream ends of the stream reach included in the lag/attenuation computations. Lags and attenuations computed from flow change events with flows during peak flow days that fall outside the limits are removed from the final compilation.

Program DAY

DS Record – Data Storage System (DSS) File

field	columns	variable	format	value	description
1	1-2	CD	A2	DS	Record identifier.
2	8	IO	I6	blank,0,1 2	DS and PN records are for the DSS input file. DS and PN records are for the DSS output file.
3	13-16	DSSYEAR	4x,A4	AN	Beginning year. Default is BEGYR from <i>JC</i> record.
4	22-24	DSSMON	5x,A3	AN	Beginning month (JAN, FEB, MAR, ... , DEC). Default is JAN.
5	25-32	DSSTYPE	A8	AN	Data type (PER-AVER, PER-CUM, INST-VAL, INST-CUM). Default is PER AVER.
6	33-40	DSSUNITS	A8	AN	Data units. Default is CFS.
7	41-48	DSSMES	I8	+ 1 blank,0,2 3 4 7 8 9	DSS message DMS file options. Default is 2. 1 Messages that DSS files are opened or closed. blank,0,2 Error and warning messages (default). 3 Pathnames to DMS file as DSS records are written. 4 Pathnames to DMS file as DSS records are read. 7 Beginning level of DMS debugging messages. 8 Intermediate level of DMS debugging messages. 9 Maximum level of DMS debugging messages.
8	49-56	DSSPN	I8	blank,0 1 +	Default pathname parts A, B, C, and F. 1 Pathname for all records specified by one PN record. + Number of PN records that follow.

PN Record – DSS Pathname Parts A, B, C, and F

field	columns	variable	format	value	description
1	1-8	CD	A2,6x	PN	Record identifier.
2	9-40	DSSA	A32	AN	Pathname Part A. Default is filename root.
3	41-72	DSSB	A32	AN	Pathname Part B. Default is control point identifier.
4	73-88	DSSC	A16	AN	Pathname Part C. Default is cfs.
5	89-104	DSSF	A16	AN	Pathname Part F. Default is that part F is not used (left blank). CPID specifies that control point identifiers are assigned to pathname part F.

Optional *PN* records, if used, follow directly behind the corresponding *DS* record. The number of *PN* records is specified by *DSSPN* in *DS* record field 8. If *DSSPN*=1, the same *PN* record is applied to all *DSS* records even if multiple *DSS* records are read from or written to the *DSS* file.

DSSA, *DSSB*, *DSSC*, and *DSSF* on the *PN* record are parts A, B, C, and F of the *DSS* record pathname. Defaults are adopted if no *PN* record is provided or if *PN* record fields are left blank.

Explanation of DS and PN Record Fields

DSS input and output files have the filenames root.DSS and rootOUT.DSS, respectively. *DS* and *PN* records specify DSS record parameters for either input or output DSS files. These parameters are described in the *HEC-DSSVue* User's Manual. The following default DSS record parameters are adopted if no *DS* and *PN* records are provided in the DIN file.

Beginning year	BEGYR from <i>JC</i> record
Beginning month	JAN
Data type	PER-AVER
Data units	CFS with exception of DAYS for lag and attenuation
DSS message level	option 2
Pathname Part A	filename root
Pathname Part B	control point identifier
Pathname Part C	DF for daily flows and IN for monthly flows
Pathname Part D	range of record blocks that contain the data series
Pathname Part E	1DAY or 1MON specifying daily or monthly time interval
Pathname Part F	not used (blank) except for FCDSS option 2

Field 2: The value for switch parameter IO entered in *DS* record field 2 specifies whether the *DS* and *PN* records are for the input file or the output file.

Field 3: The beginning year of the sequence of daily flows defaults to BEGYR from the *JC* record.

Field 4: The beginning month of the sequence of daily flows defaults to January (JAN).

Field 5: The data type is selected from the standard DSS data types described in the *HEC-DSSVue* Users Manual. The *DAY* default is PER AVER (daily average). The other options provided by DSS are PER-CUM (cumulative total during period), INST-VAL (instantaneous value), and INST-CUM (instantaneous cumulative).

Field 6: The default is CFS with the exception that DAYS is the default for lag and attenuation (FCDSS option 2 in *JC* record field 6). Other units such as AC-FT can also be specified as described in the *HEC-DSSVue* Users Manual.

Field 7: DSS writes error messages to the *DAY* message DMS file if problems occur accessing a DSS file or writing to or reading from a DSS file. Trace messages are written even if no problems occur. The extent and level of detail of trace and error messages can be controlled by DSSMES.

Field 8: A non-zero entry for DSSPN means that one or more *PN* records follow the *DS* record. The optional *PN* records allows non-default DSS pathname parts to be specified for DSS records. A DSS record of daily flows is provided for each control point. If DSSPN=1, the same *PN* record is applied to all DSS records even if multiple DSS records are read from or written to the DSS file.

Program DAY

CP Record – Control Points for Flows

field	columns	variable	format	value	description
1	1-2	CD	A2	CP	Record identifier.
2	3-8		6x		Not used.
3-12	9-88	CPID(cp)	2x,A6	AN	Control point identifiers. Up to 10 control points on each record. No limit on the number of <i>CP</i> records.

Flow sequences and quantities computed from the flow sequences are located at control points and are labeled by control point identifiers. Up to ten control point identifiers can be listed on a single *CP* record. Any number of *CP* records can be used if the number of control points exceeds ten. Control point identifiers in *DAY* have the same format used in all of the WRAP programs. Inputting and use of control identifiers vary with the different *DAY* operations as follows.

The number of control points *NCP* and job control options *JOB* are selected in *JC* record fields 2 and 7. *JOB* options 1, 2, 7, and 8 involve reading daily flows from an input file and performing specified operations on the flows at all of the *NCP* control points. With *JOB* = 1, 2, 7, or 8, the *DAY* computations for flows at each control point are independent of the flows at all other control points. However, lag/attenuation computations (*JOB*=3,4,5,6) relate flows to control points representing the upstream and downstream ends of stream reaches.

For reading daily flows, *CP* records are required with input file *INF* option 1, are optional with *INF* option 2, and cannot be used with *INF* option 3. If daily flows are read from a *DCF* file as specified by *INF* option 3 in *JC* record field 4, control point identifiers are read from the first row of the *DCF* file data tabulation. With *INF*=2, control points can be selected using *CP* records, but all control point identifiers are read from the *DF* records in the *DCF* file if no *CP* record is provided. Otherwise (*INF*=1), all relevant control points are listed on *CP* records.

With *JOB* options 3 and 4, lag and attenuation and associated quantities are computed considering just two flow sequences representing the upstream and downstream ends of a stream reach. With *JOB* = 3 or 4, *NCP* may be greater than two to allow consideration of upstream flows on multiple tributaries. The last control point represents the downstream end of the reach. The daily flows at all of the other control points are summed to obtain the total daily flows at the upstream end of the reach. The summation of flows at all upstream control points is assigned the identifier *SUMUP*.

With *JOB* options 5 and 6, lag and attenuation and associated quantities are computed for *NCP*-1 river reaches. The first reach is defined by the first and second control points listed on the *CP* records. The second reach is defined by the second and third control points. The final (*NCP*-1) reach is defined by the next-to-last and last control points listed on the *CP* records. These control points represent the upstream and downstream ends of the stream reaches.

JOB option 9 disaggregates monthly flows at a particular control point to daily flows at the same control point based on pattern daily flows at either the same or a different control point. Any number of control points can be specified on *CP* and/or *MD* records. *MD* records are required only if the monthly flows are at different control points than the pattern daily flows. The control points listed on *CP* records are applicable if monthly and pattern daily flows are at the same control point.

MD Record – Control Points for Disaggregation of Monthly Flows to Daily

field	columns	variable	format	value	description
1	1-2	CD	A2	MD	Record identifier.
2	3-8		6x		This field is not used.
3	9-16	CPMDM(cp)	2x,A6	AN	Control point identifier for monthly flows.
4	17-24	CPMDD(cp)	2x,A6	AN	Control point identifier for daily pattern flows. blank Default CPMDD(cp) = CPMDM(cp)

JOB option 9 in *JC* record field 7 activates a routine that disaggregates monthly flows disaggregates monthly flows at a control point to daily flows at the same control point based on pattern daily flows at either the same or a different control point. Any number of control points can be specified on *CP* and/or *MD* records. *MD* records are required only if the monthly flows are at different control points than the daily pattern hydrograph flows. The control points listed on *CP* records are applicable to both monthly and daily pattern flows. A *MD* record allows monthly flows at control point CPMDM(cp) to be disaggregated to daily flows at this same control point based on daily pattern flows at CPMDD(cp) entered in *MD* record fields 3 and 4. Any number of *MD* records can be employed. The total number of control points NCP for flow disaggregation includes all of those listed on *CP* records plus those additional control points listed on *MD* records.

Monthly flows are always read from the DSS or FLO input file (MFIN options 1, 2, 3). Daily flow pattern hydrographs can be read with any of the INF options, with the default being the DSS file. Disaggregation computations are the same with either MDD option selected in *JC* record field 14, but the resulting flows are stored and output differently. With the default MDD option 1, the final daily flows resulting from the disaggregation computations are the flows output with OUTF options 1, 2, and 3. With MDD option 2, the final computed daily flows are the "flow changes" output by FCDAY option 1, and the original pattern hydrograph flows are stored as the "flows" controlled by the OUTF output options. The FREQ and REGCOR options are applied to "flows" and/or "flow changes".

ED Record – End of DIN File (Last record in DIN file)

field	columns	variable	format	value	description
1	1-2	CD	A2	ED	Record identifier.

Record Sequencing in the DIN Input File

The *JC* record is always required. The optional *LP*, *DS/PN*, *CP*, and *MD* records are placed in the DIN file in any order after the *JC* record. Any number of comment ** records can be inserted anywhere. The end-of-file *ED* record is the last record in the DIN file. Any records placed after the *ED* record are not read.

Program DAY

**APPENDIX B
PROGRAM *DAILY HYDROGRAPHS (DAYH)***

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Tasks Performed by Program *Daily Hydrographs (DAYH)*

Program *DAYH* is a set of routines for developing daily naturalized stream flow sequences and routing parameters for input to *SIMD*. *DAYH* performs the following tasks.

- disaggregation of monthly naturalized flows to daily time steps and associated conversion of flow data in various formats to *DF* records (JOBDIS record)
- calibration of parameters for routing flow changes (JOBRTG record)

The naturalized flow disaggregation routines in *DAYH* are also incorporated in *SIMD* and are covered in the Chapter 3. Chapter 4 covers *DAYH* capabilities for calibration of parameters for the lag and attenuation routing method and Muskingum routing method.

Comparison of Programs *DAY* and *DAYH*

Programs *DAYH* (Appendix B) and *DAY* (Appendix A) were developed during 2005-2010 and 2016-2018, respectively. Prior to 2016, the original program, now renamed *DAYH*, was called *WRAP-DAY*. Differences and similarities between the two programs are compared as follows.

Programs *Daily Flows (DAY)* and *Daily Hydrographs (DAYH)* are described in the preceding Appendix A and the present Appendix B, respectively. *DAY* and *DAYH* are distributed as the executable files *DAY.exe* and *DAYH.exe*. However, both programs are referenced in the interface program WinWRAP as program *DAY*. Thus, the filename *DAYH.exe* must be changed to *DAY.exe* when executed within WinWRAP.

Program DAYH

Both programs use input files with filename extensions DIN, DCF, and FLO input files and output files with filename extensions DMS and DAY, though much of the data in these input and output files are different. Program *DAY* also uses DSS input and output files. Providing capabilities for working with DSS files is a key feature of the new program *DAY*. Program *DAYH* (original *DAY*) does not work with DSS files.

Calibration of routing parameters is a primary purpose of both programs. The calibration routines in *DAYH* apply objective function based optimization procedures using entire upstream and downstream hydrographs. The calibration capabilities supported by *DAY* are based on statistical analyses of upstream and downstream changes in stream flow. *DAYH* is applicable to both the Muskingum and lag/attenuation methods. *DAY* is applicable only to the lag/attenuation method. Both methodologies are based on analyzing daily streamflow hydrographs. Observed flows will typically be applied with the *DAY* methodology to capture actual flow changes caused by human actions. The *DAYH* methodology is applied with either naturalized or observed flows.

Both *DAY* and *DAYH* include options for disaggregating monthly flows to daily. *DAYH* includes essentially all the flow disaggregation options included in *SIMD*. *DAY* includes only the daily flow pattern and uniform distribution methods for disaggregating monthly flows to daily.

Both *DAY* and *DAYH* include options for statistical analyses. However, the variables analyzed and the computations performed differ between the two alternative WRAP programs.

Input and Output Files

Flow disaggregation and routing parameter calibration jobs are specified in a program *DAYH* input file with the filename extension DIN using the input records described in this appendix. The results are written to an output file with the filename extension DAY. The DAY file can be renamed with the DCF extension for use as a *DAY* or *SIMD* input file.

Program *Daily Hydrographs (DAYH)* input and output files are listed below. The DIN input file is always required, and the DMS message file and DAY output file is always automatically created. The DCF and FLO input files are used if required by options selected on the DIN file input records.

DIN	– input file with job control records	filename: root.DIN
DCF	– input file with daily flows	filename: root.DCF
FLO	– input of monthly flows	filename: root.FLO
DMS	– message file	filename: root.DMS
DAY	– output file with analysis results	filename: root.DAY

Input Records

Program *DAYH* has a main input file with the filename extension DIN that contains records controlling each flow disaggregation or calibration task. *DAYH* reads monthly and daily flows from the same FLO and DCF files read by *SIMD*. The *DAYH* computation results output file and message file have the filename extensions DAY and DMS.

Disaggregation and calibration jobs are activated by JOBDIS and JOBRTG records, respectively. The *DAYH* input DIN file may contain any number of JOBDIS and JOBRTG records and their auxiliary supporting records. Computations are performed for each job in the order that the JOBDIS and JOBRTG records are read. Any number of parameter calibration jobs for different river reaches can be included in the same DIN file.

Program *DAYH* reads monthly flows (*IN* records) and daily flows (*DF* records) from files with filename extensions FLO and DCF, respectively. The formats of the *IN* records described in the *Users Manual* and the *DF* records described in Appendix A of this *Daily Manual* are the same for *DAY*, *DAYH*, and *SIMD*. Program *DAYH* reads *IN* and *DF* records from the FLO and DCF files for only those control points specified in the *DIN* file. Records not needed are skipped. Program *DAYH* can also read monthly and sub-monthly flows in columnar or row format from the FLO and DCF files.

The input record types entered in the DIN file are listed in the table on the next page with the page numbers of the record descriptions. The remainder of Appendix D consists of explanations of each of the individual types of *DAYH* input records.

**** Record – Comments**

field	columns	variable	format	value	description
1	1-2	CD	A2	**	Record identifier

Comment ** records are ignored by the computer program. Comment lines can be inserted between any records throughout the *DAY* input DIN file.

Records for Flow Disaggregation

JOBDIS Record – Monthly to Sub-Monthly (Daily) Flow Disaggregation Job

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	JOBDIS	Record identifier
2	9-16	NTI	I8	blank, 0 + -1	<u>Number of Sub-Monthly Time Intervals in Output</u> Default is number of calendar days in each month. Constant number of intervals in each month. User defined time intervals per month to be given in the <i>NUMDAY</i> record.
3	17-24	METH	I8	blank,0,1 2 3 4 5 6 -	<u>Method for Disaggregation</u> Uniform distribution option. Linear interpolation option. Variability adjustment option. Flow pattern option. Drainage area ratio transfer option. Regression equation transfer option. Daily flows are read in columnar format and output in <i>DF</i> record format without disaggregation.
4	25-32	VOL	I8	blank,0 1	Monthly and daily input data for methods 5 and 6. Only daily input data is used for methods 5 and 6.
5	33-40	LAG	I8	blank,0,+,-	<u>Daily Flow Lag Option</u> Number of time steps to shift output daily pattern.
6	41-48	X	F8.0	+,blank,0	<u>Coefficients for METH Options 5 and 6</u> Option 5: Exponent, Default = 1.0 Option 6: Exponent, Default = 1.0
7	49-56	M	F8.0	+,blank,0	Option 5: Destination Area, Default = 1.0 Option 6: Multiplicative Coefficient, Default = 1.0
8	57-64	A	F8.0	+,blank,0	Option 5: Source Area, Default = 1.0 Option 6: Additive Coefficient, Default = 0.0
9	65-72	OUTFORM	I8	0 1 2	<u>Identifier and Formatting for Daily Flow Pattern</u> Columns of daily flows. Rows of daily flows. <i>SIMD DF</i> record formatted daily flows.
10	73-80	ID(J) J=I,N	2x,A6	AN	Identifier for the output daily flow pattern. N = 1 when METH > 0 N = ABS(METH) when METH < 0

A *JOBDIS* record results in generation of a sequence of flows with a daily or other sub-monthly time step at a single control point. Any number of flow disaggregation jobs may be included in a *DIN* file. For each job, the *JOBDIS* record is followed by the optional *NUMDAY* record and required *DFLOWS* records. The disaggregated flows are written to a *DAY* file and may be used for a subsequent *JOBMSK* record routing parameter calibration job.

Explanation of JOBDIS Record Fields

Field 2: Each of the 12 months may be divided into any number of intervals ranging from 1 to 32. The default is for the number of calendar days (28, 29 (leap year), 30, or 31) in each month to be assigned automatically. Leap years are considered automatically by assigning February 29 days instead of 28 days. Entering -1 in field 2 means that 12 integers that may vary between months are entered on a *NUMDAY* record.

Field 3: Disaggregation methods 1 through 6 are used to create a daily flow pattern from the data contained in the input file. Field 3 may be left blank if flows being simply read from the DCF file and written to the DAY file in a different format as specified in fields 9 and 10 without performing disaggregation. In this case, fields 4 through 8 of are ignored.

Field 4: Only monthly data is required in the input file if disaggregation method 1 or 2 is specified in field 3. Method 3 requires both monthly and daily input data. Method 4 requires daily data. Methods 5 and 6 can use either a combination of monthly and daily input data or simply daily input data. This is equivalent to the use of variable *DFMETHOD* on the *DC* record. If monthly input volumes are used for methods 5 or 6, then the monthly input data controls the total volume and the daily input data is used as a pattern.

Field 5: *LAG* is used to shift the output daily flow pattern forward or backward a number of time steps. *LAG* > 0 would be used if the output corresponds to a location downstream of the input data. *LAG* < 0 would be used for shifting earlier in time, common for output corresponding to a location upstream of the input data.

Field 6-8: Disaggregation options 5 and 6 activated by field 3 are based on transferring a pattern established using flows from the source location in the input file to a destination location using one of the following equations with parameter values provided in fields 6–8.

$$P_{\text{Destination}} = \left[P_{\text{Source}} \left(\frac{\text{Area}_{\text{Destination}}}{\text{Area}_{\text{Source}}} \right) \right]^x$$

$$P_{\text{Destination}} = A + M(P_{\text{Source}})^x$$

Field 9: The flows read directly or the disaggregated flows may be recorded in the DAY output file with filename extension DAY in three alternative formats. Alternatively, the flows may be used in a subsequent routing parameter calibration job without being written to the DAY file.

Field 10: The identifier *ID* is used to label the daily flow pattern recorded in the output file.

Program DAYH

NUMDAY Record – Sub-Monthly Time Intervals in Output

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	NUMDAY	Record identifier
2-13	9-104	NDAY(I) I=1,12	12I8	+	Number of time steps in months 1 through 12.

Record *NUMDAY* is only used when *NTI* is equal to -1 on the *JOBDIS* record. The number of time steps *NDAY(I)* in each month can be set to any integer from 1 through 32.

DFLOWS Record – Disaggregation Flows Format and Time Range

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	DFLOWS	Record identifier
<i>Time Range to Use from the Input Data</i>					
2	9-16	MBEGYR	I8	+	First year for reading monthly data input.
3	17-24	MBEGMT	I8	+	First month for reading monthly data input.
				Blank	Default = 1
4	25-32	MENDYR	I8	+	Last year for reading monthly data input.
5	33-40	MENDMT	I8	+	Last month for reading monthly data input.
				blank	Default = 12
6	41-48	DBEGYR	I8	+	First year for reading daily data input.
7	49-56	DBEGMT	I8	+	First month for reading daily data input.
				blank	Default = 1
8	57-64	DENDYR	I8	+	Last year for reading daily data input.
9	65-72	DENDMT	I8	+	Last month for reading daily data input.
				Blank	Default = 12
<i>Formatting for the FLO and/or DCF Input File(s)</i>					
10	73-80	INFORM	I8	blank,0	Columns of flows (<i>METH</i> > 1)
				1	Rows of flows (<i>METH</i> > 1)
				2	Monthly flows in <i>SIM IN</i> record format; columnar daily flows if needed (<i>METH</i> > 1)
				3	Monthly flows in <i>SIM IN</i> record format; <i>SIMD DF</i> record format daily flows if needed (<i>METH</i> > 1)
				-1	Multiple columnar daily flow hydrograph. This format is only used when <i>METH</i> < 0.
11	81-88	CPIN	2x,A6	AN	Identifier of <i>IN</i> records in FLO file (<i>INFORM</i> = 2,3)
12	89-96	CPDF	2x,A6	AN	Identifier of <i>DF</i> records in DCF file (<i>INFORM</i> = 3)

Time Range for Reading Data from the Input File

The FLO and DCF input files containing monthly and daily flows can potentially cover a long period-of-record, of which the user may wish to work with only a subset. Using the *DFLOWS* record, a temporal range can be specified over which flow data is adopted for the disaggregation computations. For example, monthly flow data covering a period-of-record from 1900 through 2007 and daily flows for a few decades including the record drought occurring in the 1950’s might be available. The user would be able to isolate the input data occurring in the worst year of the drought, say 1952, by selecting the appropriate starting and ending dates in fields 3 through 10 of the *DFLOWS* record.

If the disaggregation method selected does not require either monthly or daily input data, the corresponding fields on the *DFLOWS* record may be left blank. If the number of months for the daily input data is shorter than the selected period of record of the monthly input data, the daily data is repeated until the number of months in the monthly period-of-record is reached.

Columnar and Row Formatting for FLO and DCF Input Files When METH > 1

The columnar and row option for flow input is intended to accommodate the organization of flow time series with a spreadsheet. Formatted text with space delimited fields can be generated with spreadsheet programs such as Microsoft Excel.

Monthly columnar flows in the FLO file, METH > 1

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-10	MONTH	I4	+	Calendar month
3	11-14	(space)	4x	blank	
4	15-24	MFLOW	F10.0	+	Monthly flow

Monthly rows of flows in the FLO file, METH > 1

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-14	(space)	8x	blank	
3	15	MFLWS(I) I = 1,12	12F10.0	+	Monthly flows

Program DAYH

Daily columnar flows in the DCF file, *METH* > 1

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-10	MONTH	I4	+	Calendar month
3	11-14	DAY	I4	+	Calendar day
4	15-24	DFLOW	F10.0	+	Daily flow

Daily rows of flows in the DCF file, *METH* > 1

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-10	MONTH	I4	+	Calendar month
3	11-14		4x	blank	field not used
3	15	DFLOWS(I) I = 1,NDAY	12F10.0	+	Daily flows

NDAY is equal to the calendar days per month or the value given on the *NUMDAY* record.

Daily columnar flows in the DCF file, *METH* < 0

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-10	MONTH	I4	+	Calendar month
3	11-14	DAY	I4	+	Calendar day
4	15-24	DFLOW(I) I = 1, Abs(<i>METH</i>)	F10.0	+	Daily flows

Records for Calibration of Routing Parameters

JOBRTG Record – Routing Parameter Calibration Job

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	JOBRTG	Record identifier
<i>Calibration Method</i>					
2	9-16	CALIB	I8	blank, 0, 1 2 3	Genetic optimization for all upstream gages. Simulation only to compute comparison statistics. Direct solution for Muskingum parameters. Genetic optimization for lag-attenuation parameters.
3	17-24	LAT	I8	blank, 0 1	No adjustments for lateral inflow volume. Adjustments for lateral inflow based on Eq. 3.15.
<i>Optimization Objective Function</i>					
4	25-32	FUNC	I8	blank, 0, 1 2 3 4 5	Objective function option 1 (Z_1) is applied. Objective function option 2 (Z_2) is applied. Objective function option 3 (Z_3) is applied. Objective function option 4 (Z_4) is applied. Objective function option 5 (Z_5) is applied.
<i>Weighting Factor for Objective Functions 4 and 5</i>					
5	33-40	WEIGHT	F8.0	blank, 0 +	Default weighting factor of 0.80 in Eq. 4.8 or 4.9 Weighting factor (0.00 – 1.00) in Eq. 4.8 or 4.9
<i>Number and Names of Control Points</i>					
6	41-48	NGAGES	I8	+ blank, 0	Number of inflow(s) and outflow gages in calibration. Default = 2 for one inflow and one outflow gage.
7	49	GNAME(I) I=1,NGAGES	2x,A6	AN	Names assigned to the inflow and outflow control points used in the calibration.

A calibration job controlled by a *JOBRTG* record consists of determining the lag and attenuation parameters for the lag-attenuation routing method or the K and X parameters for the Muskingum routing method for one, two, or more routing reaches ending at the same location. Routing parameters are often calibrated for a single reach defined by an upstream control point and a downstream control point. However, two or more tributaries may join at a common downstream confluence. Parameters for the multiple reaches flowing into the single downstream confluence site may be calibrated simultaneously as a single *JOBRTG* record job.

The *JOBRTG* record is followed by a set of *RTYPES*, *RLOWER*, *RUPPER*, *RFIXED*, *QLOWER*, and *QUPPER* records that provide information for each of the upstream control points defining the one or more reaches that share the same downstream control point. An *RFLOWS* record is also included in the set of calibration job input records in the DIN file to describe the input hydrograph data adopted from the DCF file. The *RFLOWS* record allows a specified temporal range of flows to be adopted for the calibration computations. Defaults are activated if any of these records that support the *JOBRTG* record are not included in the set.

Explanation of JOBRTG Record Fields

Either the lag-attenuation method or Muskingum method is adopted for each routing reach as specified by the *RTYPES* record for each of the one or more upstream control points. The default (no *RTYPES* record) is the lag-attenuation method. The routing parameters for the lag-attenuation method are the lag time and attenuation time, both in sub-monthly time steps (days). The routing parameters for the Muskingum method are K in time steps (days) and the dimensionless weighting factor X. With multiple reaches sharing a common downstream control point, the different reaches are not constrained to the same routing method.

Field 2: The optimization and iterative simulation calibration methods are applicable for both lag-attenuation and Muskingum parameters. Option 3 applies only to Muskingum routing. The default optimization option consists of automatically finding optimal parameter values within the program DAY based on a genetic search algorithm incorporating the objective function selected in field 4. Option 2 in field 2 consists of performing the routing computations with fixed user-specified values of the parameters entered on the *RFIXED* record. Program DAY provides comparison statistics and objective function values that summarize the comparison between computed flows and the given flows from the DCF file at the downstream control point.

Field 3: Net incremental local inflows are the differences in flow volume between the upstream and downstream control points defining a river reach. Reach outflows at the downstream control point are adjusted to remove incremental inflows based on Equation 3.15. Objective functions 3, 4, and 5 (field 4) may work better without adjustments for incremental inflows.

Field 4: The objective functions are defined by Equations 4.2, 4.3, 4.7, 4.8, and 4.9. The optimization computations performed by the genetic algorithm are based on minimizing the selected objective function. The optimization based on the objective function selected in field 4 is activated by option 1 in field 2. The simulation activated by option 2 in field 2 includes computation of values for all of the objective functions. Field 4 is relevant only if option 1 is selected in field 2, which includes a blank field 2 as well as a 0 or 1.

Field 5: The weighting factor W is defined by Equations 4.8 and 4.9.

Field 6: The input file must contain at least one inflow hydrograph and only one outflow hydrograph. Thus, there must be at least two control points defining the upstream and downstream ends of a routing reach. Multiple reaches sharing the same downstream control point are defined by multiple upstream control points. The total number of control points entered in field 6 includes the one downstream control point and all of the upstream control points. The following *RTYPES*, *RLOWER*, *RUPPER*, *RFIXED*, *QLOWER*, and *QUPPER* records provide information associated with each of the upstream control points.

Field 7: The entries for *G NAMES(I)* are optional unless the DCF file is in the format of *DF* records. If the *DF* record format is selected on the *R FLOWS* record, *G NAMES(I)* designates the *DF* records to read from the input file. If *G NAMES(I)* are not provided, DAY proceeds with the following default names where *N* is the total number of upstream (inflow) control points and *NGAGES* is *N* + 1 downstream (outflow) control point or stream flow gaging station.

$$G NAMES(1:NGAGES) = INFL_1, INFL_2, \dots, INFL_N-1, OUTFLW$$

RTYPES Record – Type of Routing Method to Apply to the Upstream Flows

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	RTYPES	Record identifier
<i>Factor for Lag and Attenuation Calibration</i>					
2	9-16	LF	F8.0	blank,0.0 + to 1.0	Default value of 0.25 is applied. Limit factor applied to calibration of attenuation.
<i>Type of Routing Method</i>					
3	17-24	RTYPE(I) I = 1, NGAGES – 1	A8	blank, L, LA M, MK	Lag and attenuation routing method is applied. Muskingum routing method is applied.

Each of the *NGAGE* – 1 upstream control points (inflow gages) is assigned either the attenuation and lag routing method or Muskingum routing method. *NGAGE* is the total number of control points (stream flow gages) which includes one downstream gage plus any number of upstream gages. The default method is lag and attenuation. With no *RTYPES* record, the lag and attenuation method is adopted for all reaches.

Field 2: If the lag and attenuation method is selected for any of the *NGAGE* – 1 upstream control points with the *RTYPES* parameter, the value of field 2 is read. The value of field 2, *LF*, is ignored for any upstream control point assigned the Muskingum routing method. Additionally, the value of *LF* is ignored for any upstream control point assigned the lag and attenuation routing method that is also assigned a lower or upper limit on the value of attenuation via field 3 on the *RLOWER* or *RUPPER* record.

Attenuation can be defined as any real number between 1.0 and 1.0 plus the value of lag. However, the maximum theoretical value of attenuation, if allowed for consideration in the calibration process, may lead to a calibrated attenuation that distributes routed volumes over a large and unrealistic number of time steps at the downstream control point. Limiting the size of attenuation to a fraction of the value of lag plus 1.0 can improve the realism of the lag and attenuation parameters that are produced by the calibration. *LF* allows the calibration to vary the maximum valid size of attenuation as the calibration algorithm explores various sizes of lag. The dynamic resizing of the limit to attention is the difference between the application of *LF* and the *RLOWER* and *RUPPER* constraints. The value of *LF* may be specified as any positive real number less than or equal to 1.0. The default value of 0.25 is used if field 2 is zero or blank.

The following calibration range is set for any upstream control point using the lag and attenuation routing method that does not also have a specific minimum or maximum constraint applied to attenuation by the *RLOWER* or *RUPPER* records:

$$\text{Attenuation} \geq 1.0$$

$$\text{Attenuation} \leq 1.0 + LF \times \text{Lag}$$

RLOWER Record – Lower Boundary for Routing Parameters in the Optimization

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	RLOWER	Record identifier
2	16	RPARAM	I8	blank, 0 1, +	This record applies to lag or Muskingum K. This record applies to attenuation or Muskingum X.
3	24	RMIN(I) I = 1, NGAGES – 1	F8.3	0.0, + –1	Lower limit or minimum value of parameter. Default limits are applied.

RUPPER Record – Upper Boundary for Routing Parameters in the Optimization

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	RUPPER	Record identifier
2	16	RPARAM	I8	blank, 0 1, +	This record applies to lag or Muskingum K. This record applies to attenuation or Muskingum X.
3	24	RMAX(I) I = 1, NGAGES – 1	F8.3	0.0, + –1	Upper limit or maximum value of parameter. Default limits are applied.

The optional *RLOWER* and *RUPPER* records are applicable only for the optimization option set by the default first option in *JOBRTG* record field 2. Upper and lower limits are placed on the parameter values in the automatic search for parameter values that minimize the objective function selected in *JOBRTG* record field 4. If the *RLOWER* and *RUPPER* records are omitted or a value of –1 is entered on either the *RLOWER* or *RUPPER* record for one or more of the reaches, the optimization is performed with the following default constraints.

$$\begin{aligned} \text{For lag-attenuation routing:} \quad & 0.0 \leq LAG \leq 19.0 & 1.0 \leq ATT \leq 20.0 \\ \text{For Muskingum routing:} \quad & 0.5 \leq K \leq 10.0 & 0.0 \leq X \leq 0.5 \end{aligned}$$

RFIXED Record – Fixed Value for Routing Parameters

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	RFIXED	Record identifier
2	16	RPARAM	I8	blank, 0 1, +	This record applies to lag or Muskingum K. This record applies to attenuation or Muskingum X.
3	24	RFIX(I) I = 1, NGAGES – 1	F8.3	0.0, + –1	Fixed values of the routing parameter. No fixed parameter value is applied.

RLOWER, *RUPPER*, and *RFIXED* records apply to the single parameter specified in field 2 which varies between lag-attenuation routing (lag or attenuation) and Muskingum (K or X).

A *RFIXED* record is required, with positive or zero values for the routing parameters for all upstream gages, when calibration option 2 is selected for *CALIB* in *JOBRTG* record field 2.

The *RFIXED* record is optional for the optimization-based calibration option activated by 0 or 1 in *JOBRTG* record field 2. Positive values for one or more parameters entered on a *RFIXED* record will replace any positive values specified on the *RLOWER* or *RUPPER* records. The optimization may not reach the global optimum in the parameter space if one or more routing parameters are fixed with a *RFIXED* record. Generally, it is best to allow the defaults constraints to apply or define sufficiently wide margins with *RLOWER* and *RUPPER* for the optimization.

With the iterative simulation approach to calibration, *DAY* performs the routing with the parameters entered on the *RFIXED* record and creates a table of statistics and criteria functions comparing the computed flows at the downstream control point with the corresponding known flows read from the DCF file. The user reruns *DAY* with alternative values for the parameters in a trial-and-error search for optimal parameter values. Another calibration strategy is to first run *DAY* in optimization mode to obtain an initial set of parameter values which can then be further refined by iterative trial-and-error simulations using the *RFIXED* record.

RFLWS Record – Time and Formatting of the Input Flow Hydrographs

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	RFLWS	Record identifier
<i>Temporal Range</i>					
2	9-16	BEGYR	I8	+	First year for reading input hydrographs.
3	17-24	BEGMT	I8	blank, +	First month reading input hydrographs. Default = 1
4	25-32	ENDYR	I8	+	Last year for reading input hydrographs.
5	33-40	ENDMT	I8	blank, +	Last month reading input hydrographs. Default = 12
<i>Format of Input File</i>					
6	41-48	INFORM	I8	blank, 0 1	Daily flows in columnar format Daily flows (calendar days) in <i>DF</i> record format

The *RFLWS*, *QLOWER*, and *QUPPER* records control the selection of flow ranges in the use of flows from the DCF file in the calibration computations. Options controlled by these records are discussed on this page and the next page.

The switch variable *INFORM* in *RFLWS* record field 6 indicates whether the flows in the DCF file are in the format of *DC* records or the columnar format outlined below. Any number of comment ****** records may appear as a header in the DCF file.

Program DAYH

Optional Columnar Format for Sub-Monthly (Daily) Flows in the DCF File

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-10	MONTH	I4	+	Calendar month
3	11-14	DAY	I4	+	Calendar day
4	15	INFLOW(I) I = 1, NGAGES - 1	F10.0	+	Daily flows at upstream (inflow) control points (gages).
		OUTFLOW	F10.0	+	Daily flow at the outflow gage.

QLOWER Record – Lower Constraints for Upstream Flow in the Optimization

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	QLOWER	Record identifier
2	9-16		8x		Field is not used.
3	17-24, ...	QMIN(I) I = 1, NGAGES - 1	F8.0	+ blank, 0	Lower limit on upstream flows used in optimization. Default = 0.0

QUPPER Record – Upper Constraints for Upstream Flow in the Optimization

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	QUPPER	Record identifier
2	9-16		8x		Field is not used.
3	17-24, ...	QMAX(I) I = 1, NGAGES - 1	F8.0	+ blank, 0	Upper limit on upstream flows used in optimization. Default = no upper limit

The DCF file contains flows at the upstream and downstream control point locations of the inflow and outflow hydrographs for each routing reach. Inflow hydrographs are provided for each of the $NGAGE - 1$ upstream control points (inflow gages) $NGAGE$ is the total number of control points (stream flow gages) which includes one downstream gage plus any number of upstream gages. The inflows considered in the parameter calibration computations may be limited to only those flows falling within the range defined by the upper and lower limits specified on *QUPPER* and *QLOWER* records.

**Discussion of the Time Periods and Flow Ranges
Defined by *RFLOWS*, *QLOWER*, and *QUPPER* Records**

The flow hydrographs in the DCF input file may cover a long period-of-record. The entire period-of-record can be considered in calibrating the routing parameters. Alternatively, a subset of the period-of-record, ranging from a single month up to the entire period-of-record, can be selected for the calibration. Subsets of flows can also be defined by specifying minimum and/or maximum flow limits. Parameters for routing flow changes associated with flood control operations may be set separately from parameters for routing other flow changes. In addition to differentiating between flood flows and normal flows, various ranges of low to high flows may be of interest for other reasons as well in calibration studies.

The *RFLOWS*, *QLOWER*, and *QUPPER* records provide options for selecting ranges of flows for use in the calibration computations. These are ranges of the inflows at upstream control points. All flows for the entire period-of-record are included in the routing computations performed by *DAY*. However, only the selected subset of flows is included in the computation of the objective function to be minimized in the optimization algorithm based automated calibration routine. Also, only the selected subset of flows is included in the comparison statistics computed by *DAY* for use in the iterative simulation calibration strategy.

Flows might be provided in a DCF file, for example, for a period-of-record extending from 1940 to 2007. The flow regime during this long period-of-record might range from periods of severe multiple-year drought to major floods. The *RFLOWS* record can be used to isolate the one or more months containing a major flood event. A time period is specified on a *RFLOWS* record. Alternatively, minimum or maximum flow limits $QMIN(cp)$ and $QMAX(cp)$ may be specified on *QLOWER* and *QUPPER* records. A flow range can be set so that only time steps (days) with flows above a certain level (for example $QMIN(cp) = 12,500$ cfs) at the upstream control point are considered. All days are used in the lag-attenuation or Muskingum routing computations performed by *DAY* but only the days with mean daily inflows exceeds 12,500 cfs are used by *DAY* to compute the values for the objective function defined in *JOBRTG* record field 4.

The calibration of routing parameters with a *JOBRTG* record and set of supporting *DAY* input records allows for multiple upstream upstream gages (control points). Different values of $QMIN(cp)$ and $QMAX(cp)$ can be selected for application to each individual upstream gage. However, if values of $QMIN(cp)$ and/or $QMAX(cp)$ are assigned for one upstream gage but not the others, the same subset of days defined by the gage with the $QMIN(cp)$ and/or $QMAX(cp)$ assignment will be applied to all of the reaches. For example, there may be three upstream gages in a calibration job, but flood flows are defined by $QMIN(cp)$ on a *QLOWER* record for just one of the upstream gages. The optimization will proceed to find the optimal routing parameter value for each of the three reaches using the same subset of daily flows defined by the single $QMIN(cp)$.

Program DAYH

CHECKS Record – Optional Data for DMS File Output

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	CHECKS	Record identifier
2	16	C1	I8	blank, 0 +	No data written Statistics of gaged flow input data
3	24	C2	I8	blank, 0 +	No data written Routed hydrograph time series

Explanation of CHECKS Record Fields

Field 2: The following statistics for the monthly aggregated input gaged flow data are written to the DMS file for a positive value in field 2:

- Days per month within the QLOWER and QUPPER flow range
- Average monthly upstream gaged flow
- Peak daily flow per month
- Percentage of gaged upstream flow to the gaged downstream flow per month
- Average monthly downstream gaged flow

Field 3: The time series of upstream and downstream gaged flows and the routed hydrograph are written to the DMS file. The routing parameters used to generate the routed hydrograph from the gaged upstream flows are also written to the DMS file.