# Water Rights Analysis Package (WRAP) Modeling System
# Online Training Courses

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The Water Rights Analysis Package (WRAP) modeling system is documented in detail by the six manuals listed on the second and third pages of this document. Journal papers presenting more concise discussions of WRAP modeling methods and applications are also cited on the third page. The online training courses listed below and described in this document further supplement the manuals to assist model-users in learning the modeling system more expeditiously.

Course 1: Basics of Water Availability Modeling with the Water Rights Analysis Package

Course 2: WRAP Program HYD Capabilities for Compiling, Analyzing, and Updating SIM Hydrology Input Datasets

Course 3: Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

Course 4: Short-Term Conditional Reliability Modeling (CRM)

Course 5: WRAP Daily Modeling System with Additional Features for Modeling Flood Control Reservoir Operations and Environmental Flow Standards

The WRAP manuals serve as textbooks for the courses. The five courses are comprised of seven, three, four, two, and five modules. Each module consists of a lecture recorded as an audio/video MP4 file and accompanying notes from the PowerPoint presentations employed in the lectures. This document begins with five pages of introductory information followed by 296 pages of lecture notes (592 PowerPoint slides) for the 21 modules comprising the five courses.

## WRAP Modeling System

The Water Rights Analysis Package (WRAP) is the generalized simulation modeling system incorporated in the statewide Water Availability Modeling (WAM) System maintained by the Texas Commission on Environmental Quality (TCEQ). WRAP is generalized for application any place in the world. The TCEQ WAM System provides WRAP simulation input datasets for all of the river basins of Texas. A WRAP simulation input dataset for a particular river basin from the TCEQ WAM System is called a water availability model (WAM). The WRAP modeling system combines simulation of complex development, allocation, and management of the water resources of river/reservoir systems with simulation of natural river system hydrology and statistical reliability and frequency analysis methods to assess capabilities and impacts of alternative water management strategies in meeting specified scenarios of water use.

The WRAP modeling system consists of a set of computer programs and manuals that document the computer programs. The latest editions of the WRAP software and documentation, datasets for examples in the manuals, other relevant publications, and the training courses introduced here are available at the WRAP website (https://wrap.engr.tamu.edu/). The TCEQ WAM website links with the TAMU WRAP website and provides WRAP simulation input datasets for all of the river basins of Texas and an array of WAM information.

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

Most applications of the WRAP modeling system in Texas involve modifications to WRAP simulation input datasets (WAMs) from the TCEQ Water Availability Modeling (WAM) System to reflect water management strategies or projects and water use scenarios of interest. Applications outside of Texas require development of simulation input datasets.

The WRAP computer programs (https://wrap.engr.tamu.edu/) are listed as follows, with the dates of the latest versions shown in parenthesis.

*WinWRAP* (May 2019) provides an interface for executing the *WRAP* programs within the *Microsoft Windows* environment along with Microsoft programs and *HEC-DSSVue*.

*SIM* (January 2021) simulates river/reservoir water allocation/management/use systems for input sequences of monthly naturalized stream flows and reservoir evaporation-precipitation rates.

*SIMD* (January 2021) is an expanded daily version of *SIM* that includes options for flow and demand disaggregation, flow forecasting and routing, flood control reservoir operations, and environmental flow standards that include subsistence, base, and high pulse flow components.

*TABLES* (May 2019) develops summary tables, volume budgets, data listings, DSS files, tables of reliability and frequency metrics, and other tabulations for organizing, summarizing, and displaying simulation results generated by *SIM*, *SIMD*, and *SALT*.

*HYD* (May 2019) contains various routines that facilitate developing and/or updating/extending hydrologic period-of-analysis sequences of monthly naturalized stream flow and reservoir net evaporation less precipitation rates for *SIM* and *SIMD* hydrology input files.

*DAY* (July 2018) and *DAYH* (August 2013) provide methods for developing daily routing parameters and other daily hydrology input for *SIMD*.

*SALT* (July 2010) reads a *SIM* output file and a salinity input file and tracks salt constituent loads and concentrations through a river/reservoir system.

Modeling and analysis concepts and methods are described and application of the modeling system is explained by the following manuals, which are published as Texas Water Resources Institute (TWRI) technical reports (TRs). The manuals are available at both the TWRI publications website (https://twri.tamu.edu/publications/) and WRAP website (https://wrap.engr.tamu.edu/).

*Water Rights Analysis Package (WRAP) Modeling System Reference Manual*, Wurbs, TWRI TR-255, 13th Edition, 464 pages, January 2021. [*Reference Manual*]

*Water Rights Analysis Package (WRAP) Modeling System Users Manual*, Wurbs, TWRI TR-256, 13th Edition, 270 pages, January 2021. [*Users Manual*]

*Fundamentals of Water Availability Modeling with WRAP*, Wurbs, TWRI TR-283, 9th Edition, 116 pages, May 2019. [*Fundamentals Manual*]

*Water Rights Analysis Package (WRAP) Daily Modeling System*, Wurbs and Hoffpauir, TWRI TR-430, 4th Edition, 342 pages, January 2021. [*Daily Manual*]

*Water Rights Analysis Package (WRAP) River System Hydrology*, Wurbs, TWRI TR-431, 3rd Edition, 241 pages, May 2019. [*Hydrology Manual*]

*Salinity Simulation with WRAP*, Wurbs, TWRI TR-317, 89 pages, July 2009. [Salinity Manual]

The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE) maintains generalized hydrologic, hydraulic, and water management simulation models that are applied extensively by many agencies and consulting firms throughout the United States and abroad (http://www.hec.usace.army.mil/). The HEC Data Storage System (DSS) is an integral part of HEC simulation models and is also used with other non-HEC modeling systems including WRAP for efficiently working with large datasets of time series data. The WRAP programs include options for both reading and recording time series data in DSS files. *HEC-DSSVue* is a user interface program for viewing, editing, and graphing data in DSS files and performing statistical analyses and mathematical operations. *HEC-DSSVue* has been adopted as an integral component of WRAP. *HEC-DSSVue* is explained in detail by a user's manual available at the HEC website along with the software. WRAP applications of DSS and HEC-DSSVue are discussed throughout the WRAP manuals and summarized in Chapter 6 of the WRAP *Users Manual*.

## Other Publications

Appendix A of the WRAP *Reference Manual* is a "*Bibliography of WRAP Related Publications*" that lists many technical reports, graduate student theses and dissertations, book chapters, and journal and conference papers. The following journal papers included in those available at the WRAP website (https://wrap.engr.tamu.edu/) provide concise treatments of relevant topics.

R.A. Wurbs, "Water Rights Analysis Package Modeling System", *Texas Water Journal*, TWRI, Vol. 12, No. 1, June 2021. https://twj.media/

R.A. Wurbs, "Regulation and Storage of River Flows by Dams and Reservoirs", *Texas Water Journal*, TWRI, Vol. 12, No. 1, February 2021. https://twj.media/

R.A. Wurbs, "Institutional Framework for Modeling Water Availability and Allocation", *Journal of Water, Special Issue of Featured Papers on Water Resources Management, Policy, and Governance*, MDPI, Vol. 12, Issue 10, 2767, 26 pp, October 2020. https://www.mdpi.com/2073-4441/12/10/2767

## Library of Online WRAP Courses

The five courses with their 21 component modules are listed in Table 1 on page 5. The 21 audio/video recordings are MP4 files that can be played with any audio/video software. The length in minutes of the recorded presentations are tabulated in the last column of Table 1. The last 296 pages of this document are PowerPoint slides from the recorded presentations. The labels in the first column of Table 1 are found in the bottom left corner of the pages of presentation notes.

Course 1: Basics of Water Availability Modeling with the Water Rights Analysis Package

The Basics Course consisting of seven modules listed in Table 1 provides an introductory overview of the modeling system. The four other courses are based on the premise that participants are proficient with the modeling capabilities covered in the Basics Course. The *Fundamentals Manual* should be studied in detail for the Basics Course along with becoming familiar with the other WRAP manuals. The *Fundamentals Manual* concisely presents basics from the *Reference* and *Users Manuals* using an example that is expanded in other manuals. The recorded presentations reference the *Fundamentals Manual* and its example. New WRAP users should explore the modeling system by adding their own made-up new water rights and otherwise revising the example input dataset, executing the programs, and investigating simulation results.

Course 2: WRAP Program HYD Capabilities for Compiling, Analyzing, and Updating SIM Hydrology Input Datasets

The prerequisite background for this course is provided by Module 4 of the Basics Course entitled *Hydrology Features of the Modeling System*. Course 2 focuses of the capabilities of the WRAP program HYD as described in the *Hydrology Manual*. Chapters 1 and 2 of the *Hydrology Manual* are covered in Module 1. Chapters 3, 4, and 7 are covered in Module 2, and Chapters 5, 6, and 8 in Module 3. Program HYD and the *Hydrology Manual* deal primarily with developing SIM simulation hydrology input datasets of monthly naturalized stream flow volumes (IN records) and monthly net evaporation-precipitation depths (EV records). However, HYD data management and computational operations are generalized for other monthly hydrologic time series variables such as precipitation, evaporation, observed and simulated stream flows, and reservoir storage.

Course 3: Modeling Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

Course 3 builds upon the Basics Course, particularly "*Module 4 Simulation of Water Management*" of the Basics Course. *Reference Manual Chapter 3* and *Users Manual Chapter 4* are the primary textbooks for Course 3. Dams/reservoirs, conveyance facilities, institutional water allocation systems, water management strategies, and water use requirements are simulated within an organized framework of "model" water rights employing a flexible array of SIM options.

Course 4: Short-Term Conditional Reliability Modeling (CRM)

CRM covered in Chapter 8 of the *Reference Manual* is based on SIM options for dividing the hydrologic period-of-analysis into many shorter simulations all beginning with the same specified reservoir storage. TABLES storage and flow frequency and supply reliability metrics for future months over a year or perhaps longer are conditioned upon preceding reservoir storage.

Course 5: WRAP Daily Modeling System

This course and the *Daily Manual* focus on recently added features that allow simulations with a daily rather than monthly computational time step. The daily SIMD simulation model includes all of the capabilities of the routinely applied monthly SIM with new features added for stream flow disaggregation, routing and forecasting, flood control reservoir operations, and SB3 environmental flow standards that include subsistence, base, and high pulse flow components.

**Table 1**
**Modules Comprising the Five WRAP Courses**

| Module Label | Course and Module Titles | Recording (Minutes) |
|---|---|---|
| ***Basics of Water Availability Modeling with the Water Rights Analysis Package*** (The *Fundamentals Manual* is the primary textbook for this course.) | | |
| Basics M1 | Overview of WRAP/WAM Modeling | 114 |
| Basics M2 | WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records | 90 |
| Basics M3 | Executing Programs and Managing Files and Records | 62 |
| Basics M4 | Hydrology Features of the Modeling System | 70 |
| Basics M5 | Simulation of Water Management | 103 |
| Basics M6 | Simulation Model Computational Algorithms | 84 |
| Basics M7 | Supply Reliability, Flow and Storage Frequency, and Other Analyses of Simulation Results | 110 |
| ***WRAP Program HYD Capabilities for Compiling, Analyzing, and Updating SIM Hydrology Input Datasets*** (Textbook: *Hydrology Manual*) | | |
| HYD M1 | Analyses of Precipitation, Evaporation, Net Evaporation-Precipitation, Stream Flow, and Other Time Series Datasets | 78 |
| HYD M2 | Compiling SIM Input Datasets of IN and EV Records | 84 |
| HYD M3 | Updating SIM Input Datasets of IN and EV Records | 68 |
| ***Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights*** (Textbooks: *Reference* and *Users Manuals*) | | |
| Rights M1 | Simulation of Water Supply, Hydroelectric Energy Generation, And Instream Flow Requirements | 111 |
| Rights M2 | Setting Water Supply, Hydroelectric, and Instream Flow Targets | 114 |
| Rights M3 | River/Reservoir System Operations for Meeting the Targets | 96 |
| Rights M4 | SIM Options for Simulating Reservoir Operations | 154 |
| ***Short-Term Conditional Reliability Modeling*** (*Reference Manual Chapter 8 Short-Term Conditional Reliability Modeling*) | | |
| CRM M1 | Basics of Conditional Reliability Modeling (CRM) | 87 |
| CRM M2 | Probability and Correlation Methods | 102 |
| ***WRAP Daily Modeling System*** (*Daily Manual* and Chapter 4 of *Users Manual*) | | |
| Daily M1 | Introductory Overview of Daily Features | 75 |
| Daily M2 | Conversion of Monthly WAM Datasets to Daily | 77 |
| Daily M3 | Routing and Forecasting | 76 |
| Daily M4 | Flood Control Reservoir Operations | 83 |
| Daily M5 | SB3 Environmental Flow Standards | 85 |

## Basics of Water Availability Modeling with the Water Rights Analysis Package (WRAP)

## Module 1 - Overview of WRAP/WAM Modeling System

Presented by Ralph Wurbs, Ph.D., P.E.
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## Seven Modules of Course on Basics of Water Availability Modeling with WRAP

1. **Overview of WRAP/WAM Modeling System (this module)**
2. WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records
3. Executing Programs and Managing Files and Records
4. Hydrology Features of the Modeling System
5. Simulation of Water Management
6. Simulation Model Computational Algorithms
7. Supply Reliability, Flow and Storage Frequency, and Other Analyses of Simulation Results

## WRAP and WAM Systems

***Water Rights Analysis Package (WRAP)*** is a generalized modeling system developed at Texas A&M University that can be applied to any river/reservoir system, river basin, or region. WRAP provides capabilities for simulating water resources development, management, allocation, and use and performing reliability, frequency, and other analyses of simulation results.

***Texas Water Availability Modeling (WAM) System*** developed and maintained by the Texas Commission on Environmental Quality (TCEQ) and its partner agencies and contractors consists of *WRAP,* input datasets for all river basins of Texas, and other information and software tools.

## Water Availability Modeling Process

***Historical Natural Hydrology***

Period-of-analysis sequences of naturalized monthly flows at primary control points and net reservoir evaporation-precipitation rates are provided as input to the simulation. Naturalized flows are distributed from primary to secondary control points within the simulation.

***Water Resources Development, Allocation, and Use Scenario***

A specified scenario of river/reservoir system water resources development, allocation, management, and use is simulated during an assumed repetition of historical natural hydrology.

***Reliability and Frequency Metrics***

Measures of water supply reliability, stream flow and reservoir storage frequency, and other water availability information are developed.

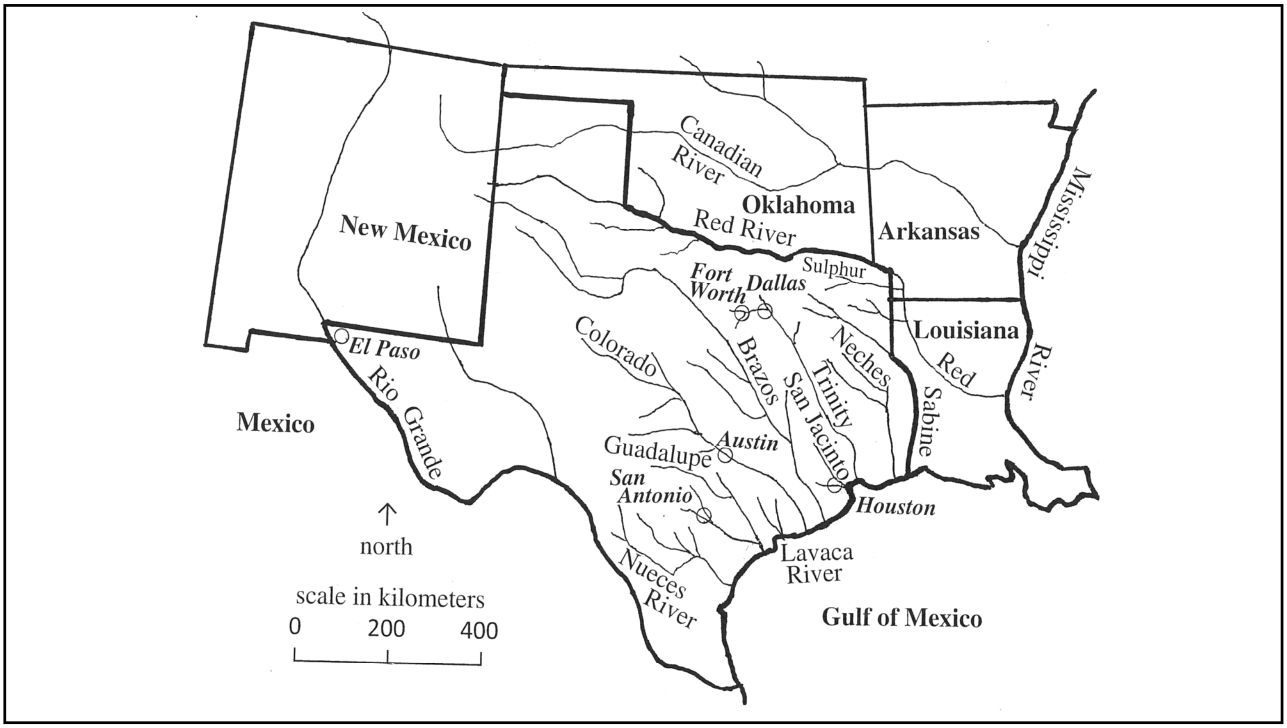
## Applications of the WRAP/WAM Modeling System

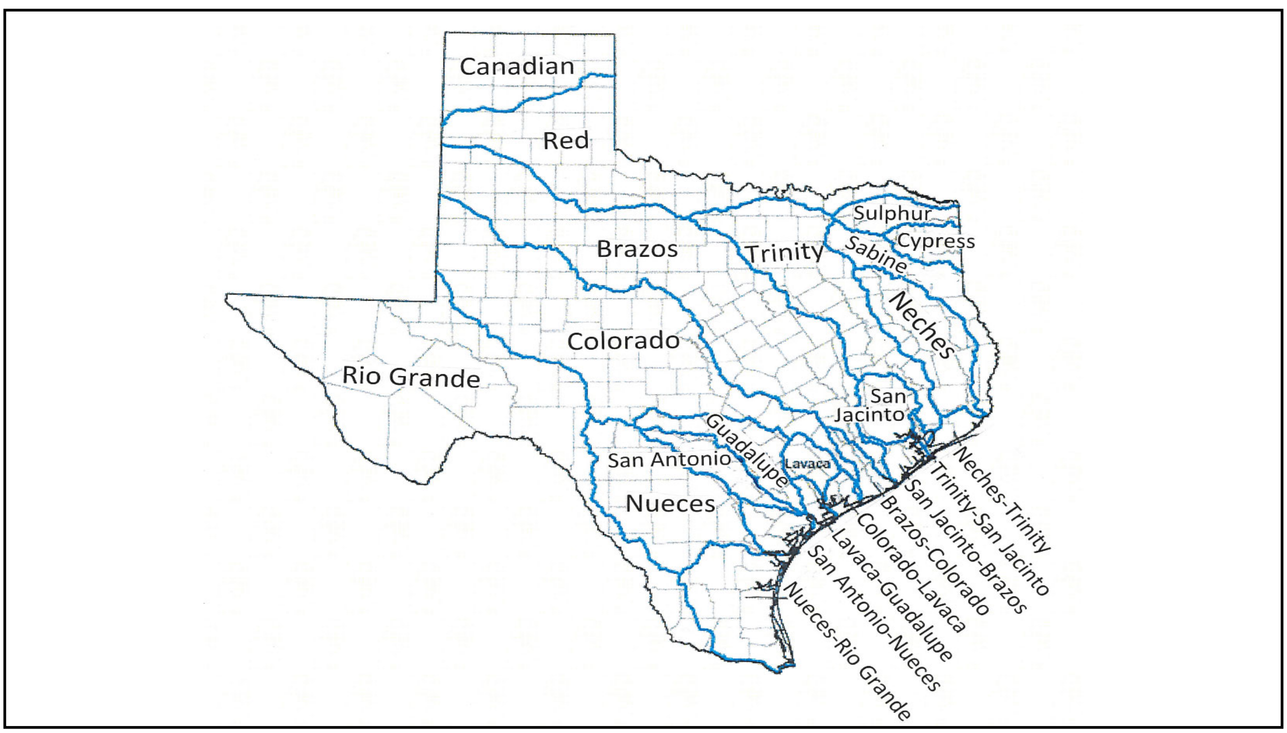
The generalized WRAP combined with a simulation input dataset from the TCEQ WAM system is called a water availability model (WAM). Variations of 20 WAMs are used for:

- Preparation and evaluation of water right permit applications.
- Regional and statewide planning studies.
- Operational planning, environmental flow studies, and other applications by water management agencies and their consultants.

## The 20 WAMs Simulate Water Resources Development, Allocation, Management, and Use

- About 3,450 permitted reservoirs (210 with authorized conservation storage capacities exceeding 5,000 acre-feet and 7 with conservation capacities exceeding 1,000,000 acre-feet), conveyance, and other constructed facilities
- About 6,200 active water right permits
- Five interstate compacts
- International treaties between Mexico and United States
- Other contracts and agreements


New Mexico
Oklahoma
Arkansas
Louisiana
Mexico
Canadian River
Red River
Sulphur
Mississippi River
Fort Worth
Dallas
El Paso
Colorado
Brazos
Neches
Trinity
San Jacinto
Red
Sabine
Rio Grande
Guadalupe
Austin
San Antonio
Houston
Lavaca River
Nueces River
Gulf of Mexico
north
scale in kilometers
0
200
400


Canadian
Red
Brazos
Trinity
Sulphur
Cypress
Sabine
Neches
Colorado
Rio Grande
San Jacinto
Guadalupe
Lavaca
San Antonio
Nueces
Neches-Trinity
Trinity-San Jacinto
San Jacinto-Brazos
Brazos-Colorado
Colorado-Lavaca
Lavaca-Guadalupe
San Antonio-Nueces
Nueces-Rio Grande

## **River Basin Characteristics** (TWRI TR-461 2014)

| WAM River Basin | Drainage Area Total (miles$^2$) | Drainage Area Texas (miles$^2$) | Annual Evap (inches) | Annual Precip (inches) |
|---|---|---|---|---|
| Rio Grande | 182,220 | 49,390 | 64.0 | 16.1 |
| Nueces | 16,700 | 16,700 | 59.6 | 24.8 |
| Guadalupe | 10,130 | 10,130 | 54.1 | 32.3 |
| Lavaca | 2,310 | 2,310 | 50.8 | 39.7 |
| Colorado | 41,480 | 41,280 | 63.1 | 24.5 |
| Brazos | 47,010 | 44,310 | 60.2 | 29.4 |
| San Jacinto | 3,940 | 3,940 | 49.0 | 46.6 |
| Trinity | 17,800 | 17,800 | 55.1 | 39.4 |
| Neches | 9,940 | 9,940 | 48.5 | 48.7 |
| Sabine | 9,760 | 7,570 | 50.9 | 47.8 |
| Cypress | 2,930 | 2,930 | 48.9 | 47.2 |
| Sulphur | 3,770 | 3,580 | 50.1 | 46.6 |
| Red | 93,450 | 24,300 | 63.4 | 25.6 |
| Canadian | 47,710 | 12,870 | 66.2 | 19.5 |
| Six Coastal | 16,050 | 16,050 | 59.0 | 29.6 |
| Total | 505,200 | 263,100 | 59.4 | 28.1 |

## **Water Availability Model (WAM) Datasets** (TWRI TR-461 2014)

| WAM | Number Control Points Total | Number Control Points Primary | Model Water Rights Number | Model Water Rights (ac-ft/yr) | Number of Reservoirs | Capacity (acre-feet) |
|---|---|---|---|---|---|---|
| Rio Grande | 957 | 55 | 2,584 | 2,228,870 | 113 | 3,499,070 |
| Nueces | 543 | 41 | 374 | 637,040 | 121 | 959,827 |
| GSA | 1,338 | 46 | 848 | 420,780 | 238 | 756.527 |
| Lavaca | 185 | 8 | 70 | 61,620 | 22 | 167,718 |
| Colorado | 2,422 | 45 | 2,006 | 2,235420 | 518 | 4,709,829 |
| Brazos | 3,842 | 77 | 1,643 | 1,519,140 | 678 | 4,015,865 |
| San Jacinto | 412 | 17 | 150 | 520,360 | 114 | 587,529 |
| Trinity | 1,398 | 40 | 1,061 | 6,617,850 | 697 | 7,356,200 |
| Neches | 378 | 20 | 399 | 621,610 | 180 | 3,656,259 |
| Sabine | 387 | 27 | 321 | 550,280 | 212 | 6,262,314 |
| Cypress | 147 | 10 | 163 | 496,230 | 91 | 877,938 |
| Sulphur | 84 | 8 | 83 | 242,070 | 57 | 718,699 |
| Red | 448 | 47 | 507 | 860,600 | 247 | 3,780,342 |
| Canadian | 85 | 12 | 56 | 94,160 | 47 | 879,824 |
| Six Coastal | 775 | 47 | 316 | 267,900 | 125 | 184,660 |
| Total | 13,401 | 500 | 10,581 | 17,373,930 | 3,460 | 37,656,830 |

## Full Authorization Scenario

- Annual water supply diversion targets authorized by water right permits distributed over the twelve months of the year.
- No return flows unless specifically authorized in water right permits.
- Reservoir storage capacities from water right permits.
- Regular water right permits only, no temporary term permits.

## Current Conditions Scenario

- Largest diversion amount in any year of recent ten year period for each permit or other approximation of recent or current water use.
- Best estimate return flows.
- Reservoir storage capacities reflecting year 2000 sedimentation or otherwise available updated data reflecting the effects of sediment deposition.
- Term permits are included as well as regular water right permits.

## Water Rights Analysis Package (WRAP) Modeling System

Generalized modeling system designed for application any where in the world.

Monthly modeling system applied with TCEQ WAM system.

Daily modeling system with features added for simulating reservoir flood control operations and high pulse flow components of environmental flow standards.

Conventional long-term simulation versus short-term conditional reliability modeling.

Salinity simulation.

Methods for developing and updating hydrology.

## Internet Sites

**https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/wam.html**

WAM information including WRAP datasets for Texas river basins

**https://https://wrap.engr.tamu.edu/**

WRAP software, manuals, and other materials

**http://twri.tamu.edu/**

Texas Water Resources Institute (TWRI) technical reports

**https://www.hec.usace.army.mil/**

USACE Hydrologic Engineering Center HEC-DSSVue

## WRAP Computer Programs

WinWRAP – Windows interface

- **Pre-Simulation Data Compilation**

HYD – hydrology data for SIM
DAY – routing parameters for SIMD
HEC-DSSVue – time series data management

- **River/Reservoir/Use System Simulation**

SIM – monthly simulation model
SIMD – daily simulation model
SALT – salinity tracking

- **Post-Simulation Organization of Results**

TABLES – frequency, reliability, summaries
HEC-DSSVue – data management, plots, mathematical operations, statistical analyses

## Auxiliary Programs

WordPad or Other Editors
Microsoft Excel
HEC-DSSVue
HEC-SSP
ArcGIS Display

## U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) Data Storage System (DSS) and HEC-DSSVue

https://www.hec.usace.army.mil/

- DSS and HEC-DSSVue are fully integrated in WRAP programs and manuals for managing time series data.
- WRAP Users Manual Chapter 6 HEC-DSS Data Storage System and HEC-DSSVue.
- HEC-DSSVue software and 465 page user's manual are available at the USACE HEC website.

## Examples of Modeling Systems that Employ HEC-DSS and the Interface HEC-DSSVue to Manage, Analyze, Plot, and Store Time Series Data

HEC-HMS Hydrologic Modeling System
HEC-RAS River Analysis System
HEC-ResSim Reservoir System Simulation
HEC-SSP Statistical Software Package
Other HEC simulation modeling systems
California Department of Water Resources CALSIM
Nature Conservancy Indicators of Hydrologic Alteration
CADSWES Riverware
Water Rights Analysis Package (WRAP)

## Primary Focus for this Course on Basics of WRAP

SIM – monthly simulation model

TABLES – reliability and frequency metrics, summary tables, and other tabulations

HEC-DSSVue – time series data management, statistical analyses, and plots

WinWRAP – interface for managing programs and data files

## WRAP Manuals

*Water Rights Analysis Package (WRAP) Modeling System Reference Manual*, TWRI TR-255, 13th Ed., January 2021.

*Water Rights Analysis Package (WRAP) Modeling System Users Manual*, TWRI TR-256, 13th Edition, January 2021.

*Fundamentals of Water Availability Modeling with WRAP*, TWRI TR-283, 9th Edition, May 2019.

*WRAP River System Hydrology*, TWRI TR-431, 4th Edition, May 2019.

*WRAP Daily Modeling System*, TWRI TR-430, 4th Edition, January 2021.

*Salinity Features of WRAP*, TWRI TR-317, July 2009.

## WRAP Manuals

- The seven modules of this course on WRAP basics rely upon the *Fundamentals Manual,* which covers essentials from the *Reference* and *Users Manuals* in a concise introductory overview manner.
- The *Users Manual* explains the detailed logistics of applying *SIM*, *SIMD*, *TABLES*, and *HEC-DSSVue*.
- The *Reference Manual* describes the basic concepts and methods incorporated in the modeling system.
- The *Daily*, *Hydrology*, and *Salinity Manuals* focus on specific aspects of the modeling system.

## Fundamentals Manual Table of Contents

## Example in the Fundamentals Manual

- 1940-2017 hydrologic period-of-analysis
- 11 primary control points, no secondary
- six reservoirs
- 28 WR record water rights
- two IF record water rights

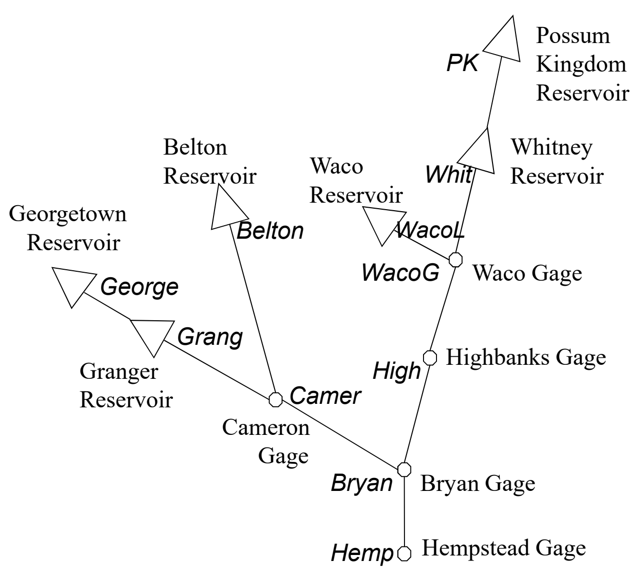



Figure 3.2 on Page 29 of the Fundamentals Manual

## Water Availability Modeling Process

***Historical Natural Hydrology***

Period-of-analysis monthly naturalized flows for the primary control points are included in the SIM simulation input dataset. Reservoir net evaporation-precipitation rate sequences and other hydrology-related data are also included in the SIM simulation input data.

Naturalized flows are distributed from primary (gaged) to secondary (ungaged) control points within the SIM simulation.

***Specified Water Development, Management, and Use Scenario***

SIM simulates a scenario of water allocation, management, and use during an assumed repetition of historical natural hydrology.

***Organization, Display, and Analyses of Simulation Results***

Simulation results are organized as metrics of supply reliability and flow and storage frequency and other measures of water availability.

## Natural Hydrology

- Naturalized flows at primary (known-flow) control points (IN records)
- Flow distribution to secondary control points (FD and WP records in DIS file)
- Channel loss factors (CP records)
- Net reservoir surface evaporation less precipitation depths (EV records)

## Water Resources Development, Allocation, Management, and Use

(WR,IF,ES,HC,WS,OR,UC,HP,SO,UP,RF,DI,EA, ML,MS,BU,FS,CV,TS,PX records)

- Water right priority systems
- Water supply diversion target options
- Return flow specifications
- Instream flow requirements
- Hydroelectric energy generation
- Reservoirs and their operation
- Multiple-reservoir/river system operations
- Multiple owner reservoirs
- Off-channel storage
- Conveyance facilities

## Water Availability Indices Developed with TABLES

- Volume reliability
- Period reliability for monthly or annual target or specified percentage of target
- Exceedance frequencies for reservoir storage, regulated flows, unappropriated flows, and other variables
- Summary tables, water budgets, and other metrics

## Optional Monthly SIM Simulation Modes

- Iterative yield-reliability (firm yield) simulations (FY record, YRO file)
- Long-term planning versus short-term conditional reliability modeling (CRM) (*Reference Manual*, Chapter 8)

## Daily Modeling Features Not Included in the Monthly SIM Simulation (Covered in *Daily Manual*)

- Naturalized flow disaggregation
- Demand target disaggregation
- Routing of flow depletions and increases
- Forecasting stream flow availability
- Flood control reservoir operations
- Environmental flow standards that include high pulse flow components

## Basics of Water Availability Modeling with the Water Rights Analysis Package (WRAP)

## Module 2 – WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records

Presented by Ralph Wurbs, Ph.D., P.E.
Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the
Texas Commission on Environmental Quality

## Seven Modules of Course on Basics of Water Availability Modeling with WRAP

1. Overview of WRAP/WAM Modeling System
2. **WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records (this module)**
3. Executing Programs and Managing Files and Records
4. Hydrology Features of the Modeling System
5. Simulation of Water Management
6. Simulation Model Computational Algorithms
7. Supply Reliability, Flow and Storage Frequency, and Other Analyses of Simulation Results

WRAP software, manuals, and input datasets for the examples in all of the manuals including the dataset for the example in the Fundamentals Manual are available at the WRAP website.

**https://wrap.engr.tamu.edu/**

The original WRAP website used for many years was replaced in January 2021 by a new website accessed at the new address shown above.

## Fundamentals Manual Table of Contents

## Example in the Fundamentals Manual

- 1940-2017 hydrologic period-of-analysis
- 11 primary control points, no secondary
- six reservoirs
- 28 WR record water rights
- two IF record water rights

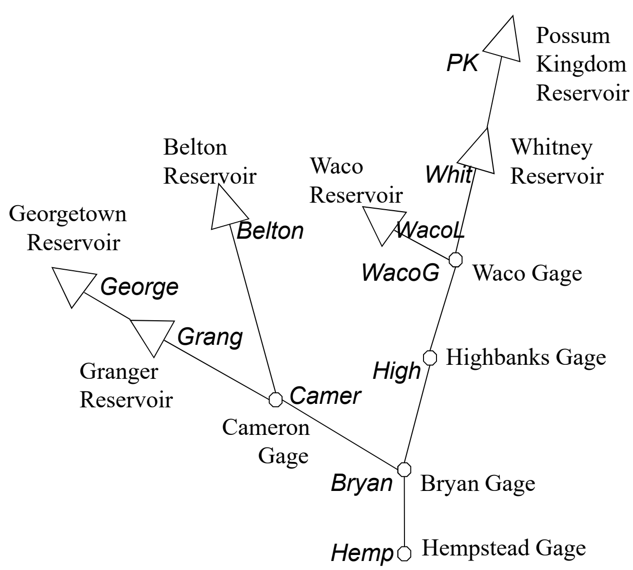



Figure 3.2 on page 29 of the Fundamentals Manual

## Program SIM Input and Output Files

| Input Files | Output Files |
|---|---|
| *root*.DAT | *root*.MSS |
| *root*.DIS | *root*.OUT |
| *root*.FLO | *root*.DSS |
| *root*.EVA | *root*.YRO |
| *root*.DSS | |

A complete list of all WRAP input and output files is provided as Table 1.2 of the Users Manual. An abbreviated list of SIM and TABLES input and output files is found in Table 1.2 on page 5 of the Fundamentals Manual.

## SIM Input and Output Files for Example

**SIM Input Files**

FundExam.DAT
FundExamHYD.DSS

Note: The hydrology DSS file can be replaced with:

FundExam.FLO
FundExam.EVA

**SIM Output Files**

FundExam.MSS
FundExam.OUT
FundExam.DSS
FundExam.YRO

## Program TABLES Input and Output Files

(Table 1.2 on Fundamentals Manual Page 5)

| **Input Files** | **Output Files** |
|---|---|
| FundExam.TIN | FundExam.TMS |
| FundExam.OUT | FundExam.TOU |
| FundExam.DAT | FundExam.DSS |

## Input Records

- Input records are recorded in plain text files.
- Each *SIM* input record begins with a two-character record identifier. Each *TABLES* input record begins with a four-character record identifier.
- Each variable must be entered within a specified set of columns (field width).
- Records, variables, variable values and field widths are specified in the Fundamentals and Users Manual.
- Tabs are not read by the WRAP programs. Always use blank spaces rather than tabs.

# IN Records a SIM FLO File

FundExam.FLO - WordPad

File Edit View Insert Format Help

```
**   File FundExam.FLO - Naturalized Flows in acre-feet for the Example Dataset
**
**     CP     Year    Jan      Feb      Mar      Apr      May      Jun      Jul      Aug      Sep      Oct
**
IN     PK     1940  10094.   10172.     836.   16772.  114403.  289797.   45691.  242432.   54126.    3317.   79
IN     PK     1941   9910.   75951.   64391.  201160.1267722.  627107.  140733.  116128.  103454.  758197.  137
IN     PK     1942  26025.   13531.   14131.  468326.  139111.  151003.   15609.   23207.  166710.  325061.   35
IN     PK     1943  16615.   10142.   26089.   57649.   17708.   70893.   14538.    1024.    1980.    2856.
IN     PK     1944   3922.   13485.   45426.   23584.   54063.   50477.   32829.   17198.   25757.   54397.   12
IN     PK     1945  11431.   12504.  119261.   98987.   28038.   42120.  151123.   12303.    6233.   94508.    6
IN     PK     1946  19379.   15155.    9356.    8718.   29334.   44444.   28702.   58775.  212225.  111731.   61
IN     PK     1947  13623.    6554.   12028.    8687.  479473.   54788.    8891.    2760.   13188.   34369.    9
IN     PK     1948   3748.    5871.   25281.    8583.   32120.  127828.  115435.   14256.    7234.   18154.   10
IN     PK     1949   2099.   12673.   13813.   15030.  320457.  176336.   16034.   15527.   93914.   63534.    9
IN     PK     1950   3037.    7982.    2631.   57812.  202611.   42025.  196046.   73270.  146770.   19577.
IN     PK     1951   2761.    4274.    1833.    2048.  112117.  152042.   24098.   25353.   24699.       0.
IN     PK     1952   484.0     55.0    820.0   7073.0  16673.0  13986.0  14388.0   5388.0   5349.0   2645.0   45
IN     PK     1953    986.     576.    6662.    3116.   79575.       0.  265689.   89225.   17631.  252122.   25
IN     PK     1954   5182.    5221.    1602.  107969.  379232.   43287.   14581.   13551.     492.     539.   18
IN     PK     1955   3906.    5662.   16837.   14931.  214934.  220077.   63325.   23962.  480744.  351752.   15
IN     PK     1956 15225.0   4032.0     23.0   2811.0  42134.0  14472.0      0.0      0.0   1468.0   6654.0  179
IN     PK     1957      0.  224472.    8925.  724847.1794495.  436949.   36297.   13320.   18908.  139484.  116
```

# EV Records in a SIM EVA File

FundExam.EVA - WordPad

File Edit View Insert Format Help

```
**   File FundExam.EVA - Net Evaporation-Precipitation Rates in feet/month for the Example Dataset
**
**     CP     Year    Jan      Feb      Mar      Apr      May      Jun      Jul      Aug      Sep      Oct      Nov
**
EV     PK     1940   0.159    0.055    0.459    0.191    0.266    0.106    0.834    0.524    0.651    0.536   -0.149   -
EV     PK     1941   0.134   -0.161    0.179    0.011   -0.028    0.079    0.519    0.340    0.485   -0.199    0.316
EV     PK     1942   0.221    0.251    0.380   -0.380    0.247    0.361    0.800    0.597    0.226   -0.069    0.388
EV     PK     1943   0.225    0.325    0.116    0.394    0.275    0.490    0.761    1.038    0.587    0.498    0.370   -
EV     PK     1944  -0.019   -0.067    0.226    0.357    0.212    0.711    0.702    0.773    0.614    0.345    0.112
EV     PK     1945   0.094   -0.032   -0.008    0.109    0.578    0.527    0.388    0.813    0.593    0.205    0.425
EV     PK     1946  -0.025    0.136    0.258    0.372    0.246    0.570    0.998    0.871    0.153    0.396    0.074
EV     PK     1947   0.114    0.247    0.112    0.122    0.082    0.679    0.969    0.901    0.877    0.438    0.202
EV     PK     1948   0.141   -0.038    0.271    0.434    0.252    0.428    0.684    0.896    0.820    0.526    0.451
EV     PK     1949  -0.170   -0.020    0.146    0.112   -0.135    0.377    0.806    0.593    0.454    0.074    0.442
EV     PK     1950   0.090    0.150    0.493    0.148    0.052    0.482    0.116    0.622    0.247    0.652    0.550
EV     PK     1951   0.209    0.069    0.291    0.298    0.043    0.115    0.728    0.835    0.672    0.444    0.247
EV     PK     1952   0.212    0.229    0.238    0.138    0.177    0.815    0.876    1.284    0.867    0.820    0.130
EV     PK     1953   0.230    0.188    0.177    0.264    0.252    0.946    0.608    0.658    0.794    0.015    0.195
EV     PK     1954  -0.003    0.328    0.381    0.062   -0.019    0.594    0.714    0.777    0.630    0.316    0.127
EV     PK     1955   0.031    0.089    0.207    0.337   -0.033    0.222    0.594    0.548    0.074    0.382    0.286
EV     PK     1956   0.044    0.046    0.401    0.361    0.162    0.653    0.807    0.780    0.707    0.291    0.195
EV     PK     1957   0.093   -0.106    0.114   -0.543   -0.709    0.259    0.529    0.649    0.244   -0.117   -0.222
EV     PK     1958  -0.006    0.070   -0.035   -0.039    0.052    0.453    0.283    0.464    0.118    0.205    0.153
EV     PK     1959   0.141    0.117    0.367    0.283    0.122   -0.102    0.189    0.476    0.342   -0.310    0.215   -
EV     PK     1960  -0.051    0.061    0.144    0.248    0.237    0.510    0.283    0.387    0.284    0.053    0.286   -
```

## SIM Input DAT File (Fundamentals Manual Page 57 )

```
**   File FundExam.DAT
**   SIM Input File for the Example in the Fundamentals Manual
**   May 2019
**
**       1         2         3         4         5
**3456789012345678901234567890123456789012345678901234556
**-----!-------!-------!-------!-------!-------!-------!
** JD Record Fields
**   NYRS    YRST  ICHECK   CPOUT   OUTWR OUTFILE  ADJINC
JD    78    1940       1       1       1               6
JO     6
RO    -1
OF     1   0   1
**
**   Activation of the FY record results in a yield-reliability
**   table written to a file with the name FundExam.YRO.
**
**FY       200000.  10000.   1000.    100.   WR-24
**
```

## Use Coefficient UC Records in DAT File (Page 57)
(UC Record Description on Fundamentals Manual Page 83)

```
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.
```

## Control Point CP Records in DAT File (Page 57)
(CP Record Description on Fundamentals Manual Page 84)

```
**      1         2         3         4         5         6         7
**3456789012345678901234567890123456789012345678901234567890123456789012
**-----!-------!-------!-------!-------!-------!-------!-------!-------!
CP    PK    Whit                                                 0.061
CP  Whit   WacoG                                                 0.009
CP WacoL   WacoG                                                 0.000
CP WacoG    High                                  none           0.010
CP  High   Bryan                                  none           0.014
CPBelton   Camer                                                 0.028
CPGeorge   Grang                                                 0.008
CP Grang   Camer                                                 0.015
CP Camer   Bryan                                  none           0.036
CP Bryan    Hemp                                  none           0.025
CP  Hemp                                          none
**
```

## IF and WR Record Water Rights (Pages 57-59, 86-91)

```
**
** 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                  990000                                WR-5            Refill
WS  Whit 627100.                         379000.
**
```

## **SV & SA and PV & PE Records** (Pages 59, 92)

```
**  Reservoir Storage Volume (acre-feet) versus Surface Area (acres) Tables
**
SVBelton      0.    40.    160.    650.   1100.   1800.  20900.  58700. 123500. 218100. 304170. 457600.
SA            0.    17.     32.     63.    110.    200.   1760.   3270.   5290.   7580.   9261.  12258.
**
SVGeorge      0.     3.     97.    280.    640.   1250.   2610.   4170.   6310.  11500.  22900.  37100.
SA            0.     2.     19.     45.     77.    130.    237.    323.    410.    620.    958.   1310.
**
SV Grang      0.    76.    272.    960.   2200.   3460.   5310.   7030.  10310.  23950.  46600.  65500.
SA            0.    16.     52.    180.    344.    500.    750.    980.   1230.   1828.   3280.   4400.
**
SV    PK      0.   236.    865.   3579.  10447.  22038.  25810. 147410. 298092. 504100. 547414. 570240.
SA            0.    60.    216.    525.    962.   1403.   1500.   5675.   9875.  14440.  15803.  17700.
**
SV WacoL      0.     8.     36.   1438.   3509.   4804.  17091.  29704. 105675. 152500. 207106. 304510.
SA            0.     4.     12.    160.    338.    562.   2741.   3524.   5986.   7270.   8465.  11049.
**
SV  Whit      0.     9.   1145.   4843.  51240. 157245. 379108. 427400. 559219. 627100. 807330. 1120975
SA            0.    22.    237.    507.   3210.   7500.  15760.  16450.  21740.  23560.  28070.  34920.
**
**  Reservoir Storage Volume (acre-feet) versus Elevation (feet) Table for Hydropower at Lake Whitney
**
PV  Whit   2630.  19600.  41710.  79990. 143200. 229400. 363600. 473100. 601800. 782000. 1095000 1473000
PE        448.8   470.0   480.0   490.0   500.0   510.0   520.0   527.0   533.0   540.0   550.0   560.0
ED
```

## **TABLES Input Records** (Pages 61, 95-108)

```
**   File FundExam.TIN
**   TABLES Input File for the Example in the Fundamentals Manual
**       1         2         3         4         5         6
**  567890123456789012345678901234567890123456789012345678901234
****---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!
**    Water rights summary table.
1SUM   2
**    Time series tables of naturalized, regulated, and unappropriated flows.
2NAT   1   2   1   0   1
IDEN    Hemp
2REG   1   2   1   0  -1
2UNA   0   2   0   0   3
IDEN    Hemp    Whit    High   Camer
****---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!
**    Time series output records of total storage in DSS file.
2STO   0   4   0   0   0   0   0   1
```

## TABLES Input Records (Pages 61, 95-108)

```
**    Frequency tables for flow, storage, and reservoir surface elevation.
2FRE   1
2FRE   3
2FRE   2   0   0   2
2FRE   4
2FRE  -4
2FRQ   7   0   7    Whit   518.0   520.0   524.0   528.0   530.0   532.0   533.7
****---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!
**    Reliability for water supply diversions and hydroelectric energy.
2REL
2REL   0   0   1
2REL   0   0   2   1
IDEN    Whit
2REL   0   0   3  11
IDEN      PK WhitneyWacoLake  Belton  George Granger CameronWacoGage
IDENHighbank   Bryan    Hemp
****---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!
**    Summary table for the entire river basin.
2SBA
ENDF
```

## Water Availability Indices Developed with TABLES

(2REL and 2FRE records on pages 103-106 of Fundamentals Manual)

- Volume reliability
- Period reliability for target or specified percentage of target
- Exceedance frequencies for reservoir storage, regulated flows, unappropriated flows, and other variables
- Other metrics

## Data Storage System (DSS) Pathname Parts for SIM and SIMD Input DSS Files

(Users Manual Table 6.6)

A – hydrology filename root
B – control point identifier
C – DF (daily flow), IN (monthly naturalized flow), EV (evap-precip), FA (flow adjustments), HI (hydrologic index), TS (target series)
D – date range covered by data
E – 1MON for monthly data or 1DAY for daily data
F – pathname part F is not used for SIM and SIMD input data

## Data Storage System (DSS) Pathname Parts for SIM and SIMD Output DSS Files

(Users Manual Table 6.7)

A – filename root
B – control point identifier
C – type of data such as NAT, REG, UNA, STO, DIV, or DEP (defined in Table C1 on page 80 of Fundamentals Manual and page 47 of Users Manual) combined with –CP, -WR, or –RE (control point, water right, reservoir)
D – date range covered by data
E – 1MON for monthly data or 1DAY for daily data
F – water right or reservoir identifiers or CP information

## Detecting and Correcting Errors in Input Data Files

Fundamentals Manual, Chapter 5 Correcting Errors in WRAP Input Data Files.

Reference Manual, Chapter 9 Detecting Errors and Irregularities in Data Files.

Users Manual, Chapter 2 (pages 23-26), section entitled Locating Errors in the Input Data Files

## Trace, Warning, and Error Messages Recorded in the Message File

- Trace messages track progress in reading input data, performing computations, and recording results in output files.
- Warning messages alert model-users to peculiarities without stopping program execution.
- Error messages are accompanied by termination of program execution.

## SIM Message File FundExam.MSS

```
WRAP-SIM MESSAGE FILE
*** Starting to read file FundExam.DAT
*** JD record was read.
*** JO record was read.
*** Reading RO records.
*** OF record was read.
*** Starting to read UC records.
*** Finished reading UC records.
*** Starting to read CP records.
*** Finished reading CP records.
*** Starting to read IF/WR records.
*** Finished reading IF/WR records.
*** Starting to read SV/SA records.
*** Finished reading SV/SA records.
*** Starting to read PV/PE records.
*** Finished reading PV/PE records.
*** Following input to be read later from DSS file: FundExamHYD.DSS
      IN and EV records (JO record INEV option 6)
*** Finished reading file FundExam.DAT
```

## SIM Message File (Continued)

```
*** Starting to open remaining files.
*** Opened file FundExam.OUT
*** Finished opening text (non-DSS) files.
   -----DSS---ZOPEN:  Existing File Opened,  File:
FundExamHYD.dss
              Unit:   25;  DSS Versions - Software: 6-WA, File: 6-QF
*** Starting to read 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: FundExamHYD.dss
        Pointer Utilization:  0.09
        Number of Records:    675
        File Size:   3424.2  Kbytes
        Percent Inactive:  25.4
*** Finished ranking water rights in priority order.
```

## SIM Message 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
      2 instream flow rights (IF records)
    28 all water rights except IF rights (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 storage-elevation tables (PV/PE records)
*******************************************************
```

## SIM Message File (Continued)

```
*** Beginning annual loop.
*** End of input data trace.
*** Negative incremental flow adjustments are performed for the first year.
*** Beginning to write simulation results to DSS file.
     -----DSS---ZOPEN:  Existing File Opened,  File: FundExam.dss
                   Unit:   26;  DSS Versions - Software: 6-WA, File: 6-WA
*** Beginning control point output to DSS file.
*** Beginning water right output to DSS file.
*** Beginning reservoir output to DSS file.
*** Finished writing simulation results to DSS file.
   -----DSS---ZCLOSE Unit:   26,   File: FundExam.dss
                  Pointer Utilization:  0.40
                  Number of Records:   1832
                  File Size:   1952.2  Kbytes
                  Percent Inactive:   0.0
Date:            02/14/2019
Beginning Time:  16:23:04
Ending Time:     16:23:05
***** Normal Completion of Program WRAP-SIM *****
```

## Example Error Message in MSS File

```
WRAP-SIM MESSAGE FILE

*** Starting to read file fundexam.DAT

ERROR: Fortran IOSTAT error occurred reading an
       input record with CD identifier of JD
       IOSTAT status variable =    64
       Stopped from Subroutine READDAT due to error.

The first 82 characters of each of the last two records read are as follows:
**  NYRS    YRST  ICHECK   CPOUT   OUTWR OUTFILE  ADJINC
JD  74    1940       1      -1      -1               4

*** Execution of SIM terminated due to an input error.
*** IOSTAT status variable (error code) =    64
*** JD record contains data in wrong format.
```

## Examples of Warning Messages in the MSS File

WARNING: JD field 4 ICHECK is 8 but there are no dual simulation rights.
WARNING: SV/SA records are provided but not assigned to a reservoir.
WARNING: There is a reservoir (WS record) but IFMETH is not 3 or 4 for IF right ___________
WARNING: The beginning of simulation storage specified for reservoir _____ exceeds its capacity. The initial storage is set at capacity.
WARNING: No storage capacity on WS record for reservoir _________ for water right _________
WARNING: The TOCOMB=DIV option for right _______ involved dividing by zero and thus was skipped.
WARNING: EA record should be used only with type 1 rights. ____ is type ___
WARNING: _____ on CO record is not on any CP record.

## ICHECK Options Selected in JD Record Field 4

Users Manual Table 2.3
Reference Manual Table 9.2

blank, 0 – normal trace, reduced error, and no warning checks.

1 – normal trace and complete error and warning checks.

2 through 7 – specified records written to MSS file as read.

8 through 14 – other options defined in Users Manual Table 2.3 and Reference Manual Table 9.2.

## Seven Modules of Course on Basics of Water Availability Modeling with WRAP

1. Overview of WRAP/WAM Modeling System
2. WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records
3. **Executing Programs and Managing Files and Records**
4. Hydrology Features of the Modeling System
5. Simulation of Water Management
6. Simulation Model Computational Algorithms
7. Supply Reliability, Flow and Storage Frequency, and other Analyses of Simulation Results

## Module 3 Demonstration Using the Example in the Fundamentals Manual

- Executable Computer Programs (WinWRAP.exe, SIM.exe, TAB.exe, HEC-DSSVue.exe)
- SIM input files (DAT and DSS files)
- SIM input records contained in the input files
- SIM output files (MSS, OUT, and DSS files)
- TABLES input files (OUT and TIN files)
- TABLES input records contained in TIN file
- TABLES output files (TMS, TOU and DSS files)

## Programs Used in the Module 3 Demonstration

- **SIM** – monthly simulation model
- **TABLES** - reliability and frequency metrics, summary tables, and other tabulations
- **HEC-DSSVue** – time series data management, statistical analyses, and plots
- **WinWRAP** – interface for managing programs and data files
- **Microsoft WordPad** – viewing and editing files

## Basics of Water Availability Modeling with the Water Rights Analysis Package (WRAP)

## Module 3 – Executing Programs and Managing Files and Records

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Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the

Texas Commission on Environmental Quality

## Seven Modules of Course on Basics of Water Availability Modeling with WRAP

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## Module 3
## Executing Programs and Managing Files and Records

Module 3 is a demonstration applying WinWRAP, SIM, TABLES, and HEC-DSSVue with the WAM example presented in the Fundamentals Manual as discussed in the preceding Module 2. The audio/video recording displays the computer monitor as the programs are executed and records in the input and output files are explored. The system schematic and listings of computer programs and files employed in the Module 3 demonstration are replicated as follows for convenient reference.

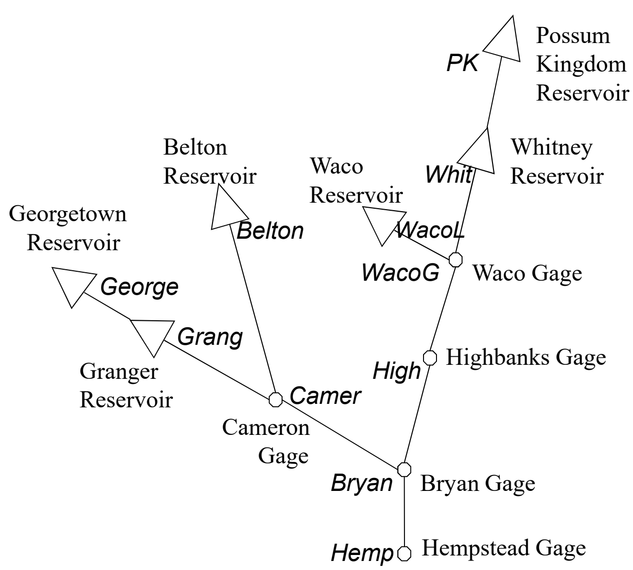



**Figure 3.2 on page 29 of the Fundamentals Manual**

## Module 3 Demonstration Using the Example in the Fundamentals Manual

- Executable Computer Programs (WinWRAP.exe, SIM.exe, TAB.exe, HEC-DSSVue.exe)
- SIM input files (DAT and DSS files)
- SIM input records contained in the input files
- SIM output files (MSS, OUT, and DSS files)
- TABLES input files (OUT and TIN files)
- TABLES input records contained in TIN file
- TABLES output files (TMS, TOU and DSS files)

## Programs Used in the Module 3 Demonstration

**SIM** – monthly simulation model

**TABLES** – reliability and frequency metrics, summary tables, and other tabulations

**HEC-DSSVue** – time series data management, statistical analyses, and plots

**WinWRAP** – interface for managing programs and data files

**Microsoft WordPad** – viewing and editing files

## Seven Modules of Course on Basics of Water Availability Modeling with WRAP

1. Overview of WRAP/WAM Modeling System
2. WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records
3. Executing Programs and Managing Files and Records
4. **Hydrology Features of the Modeling System (this module)**
5. Simulation of Water Management
6. Simulation Model Computational Algorithms
7. Supply Reliability, Flow and Storage Frequency, and Other Analyses of Simulation Results

## River System Hydrology

- The WRAP program HYD and HEC-DSSVue provide flexible sets of tools for developing monthly naturalized flows (*IN* records) and evaporation less (optionally adjusted) precipitation rates (*EV*) records.
- Observed flows are available from the U.S. Geological Survey (USGS) National Water Information System (NWIS) website and other sources.
- Monthly evaporation and precipitation data are available from Texas Water Development Board (TWDB) databases and other sources.

## Naturalized Stream Flow

Naturalized flows input on *IN* records in a FLO or DSS file are a *homogeneous* time series of monthly flows in a SIM simulation input dataset that do not include effects of the water development, management, and use that are to be simulated in the SIM simulation.

*Stationarity* (homogeneity over time) – flows represent a uniform condition of river basin and water resources development, long-term climate, and water use.

## Net Reservoir Evaporation Less Precipitation

- Evaporation from and precipitation falling directly on the reservoir water surface are combined as net evaporation minus precipitation.
- Net evaporation-precipitation rates in are recorded on *EV* records in a EVA file or DSS file in units of feet/month.
- SIM uses net evaporation-precipitation depths, along with a calculation of reservoir surface area, to determine the volume of water lost or gained due to the evaporation from and adjusted precipitation on the reservoir water surface.

## Precipitation Adjustments

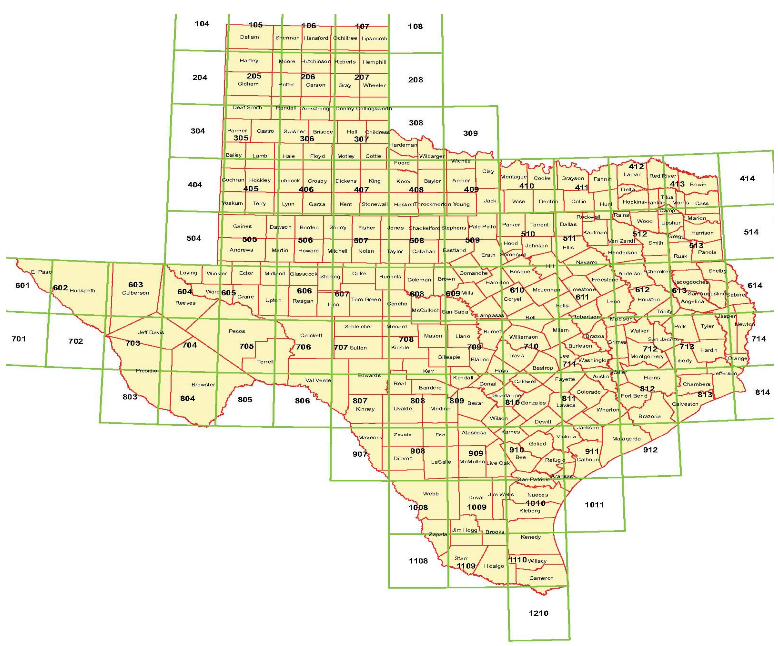
Options are available to prevent "double counting" the portion of the precipitation falling on a reservoir water surface that is also included in naturalized stream flow inflow to the reservoir.

JD record EPADJ and CP record EWA

FD and WP record watershed area

(Reference Manual, Chapter 3 Hydrology, pages 46-47)

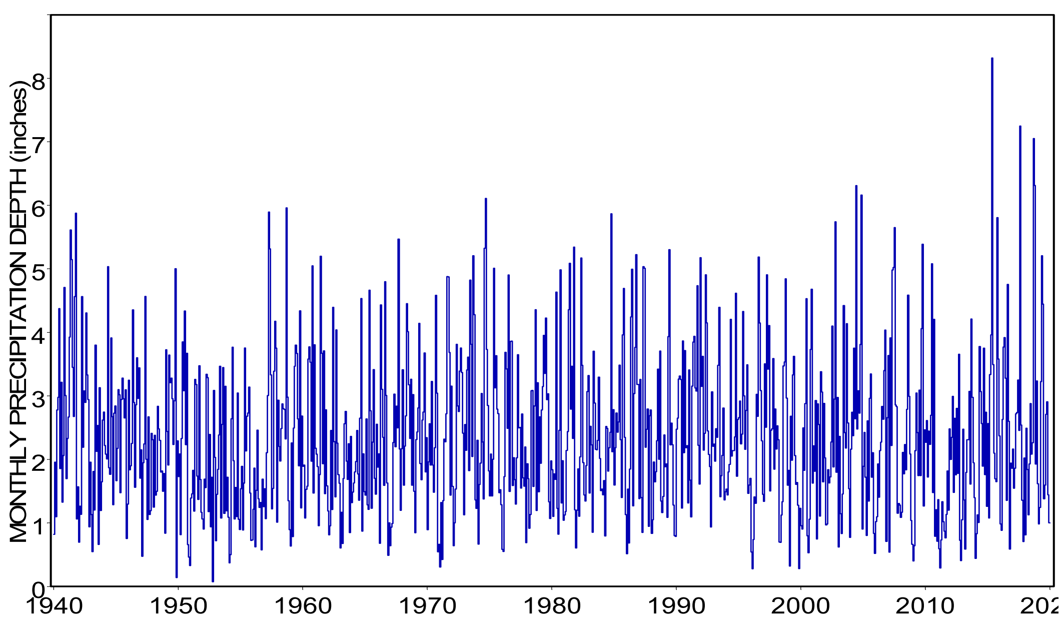
## TWDB Quadrangle Monthly Evaporation and Precipitation Data

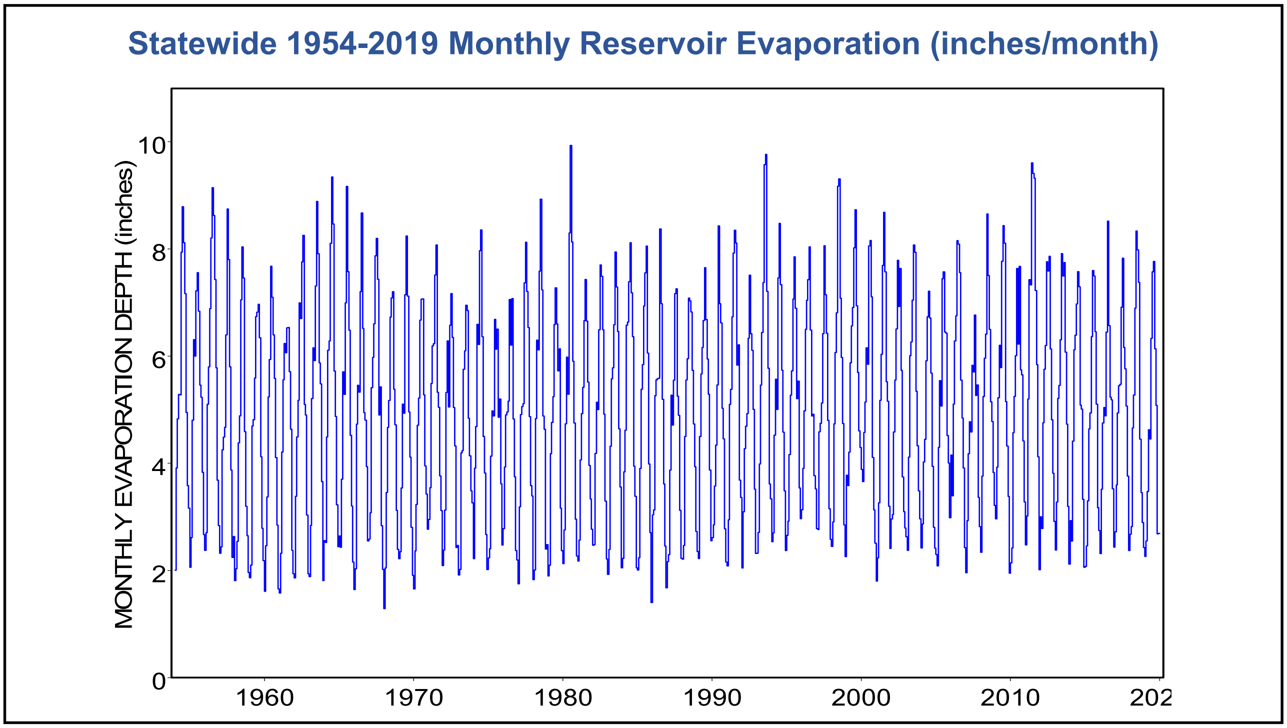


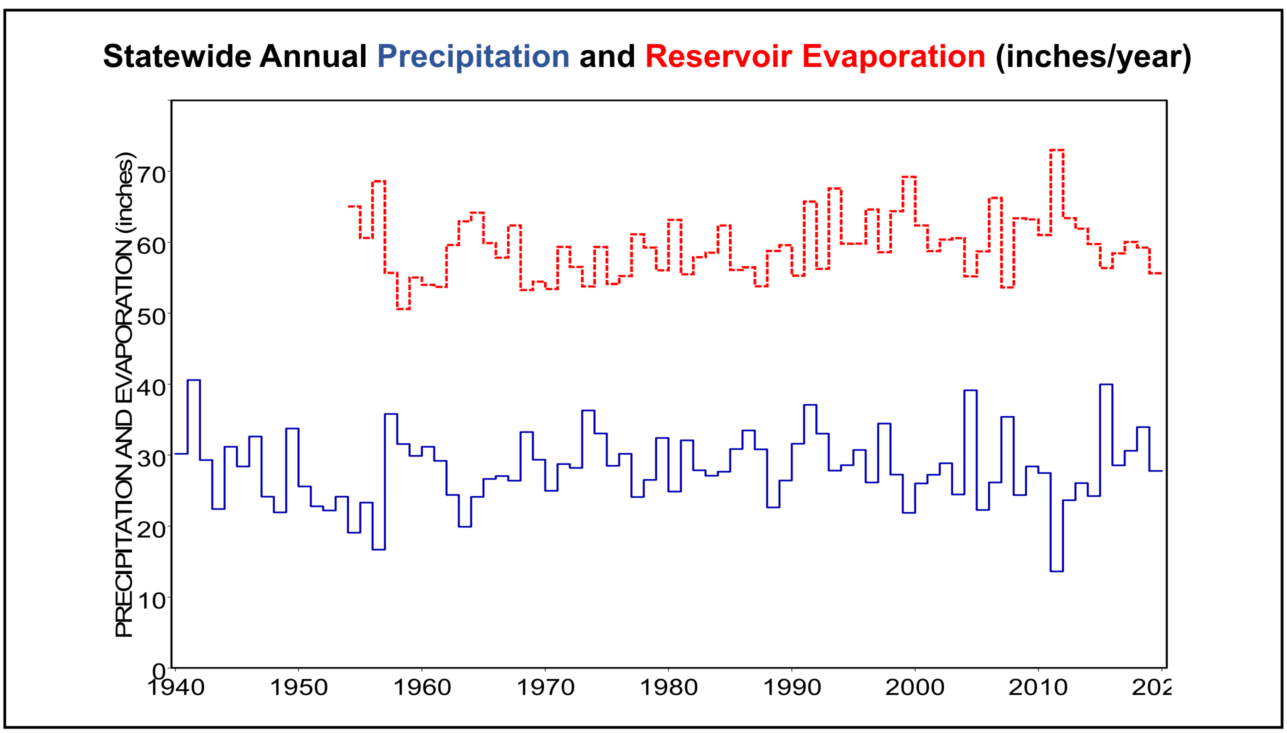
## Mean Annual Precipitation (top) and Reservoir Evaporation (bottom) Depths (inches/year) for the 92 Quads Defined in the TWDB Database

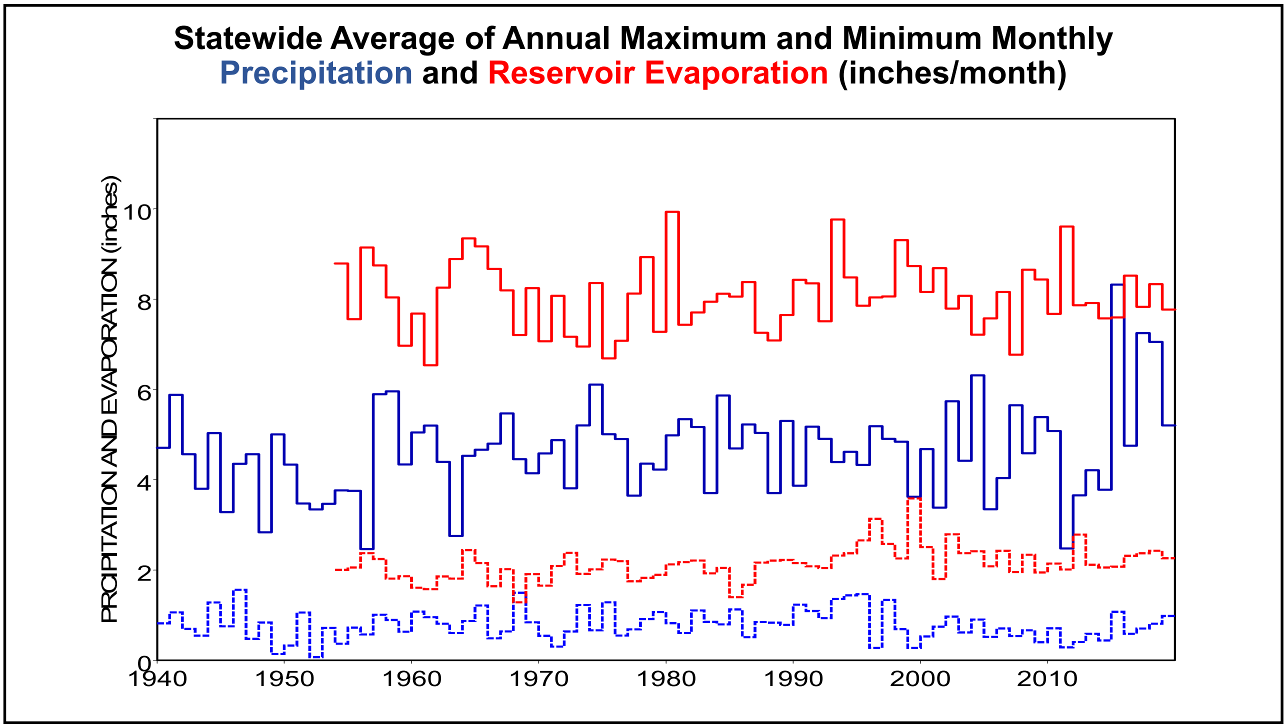
| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 16.9 | 17.8 | 18.7 | 21.0 | 24.1 | | | | | | |
| | | | 60.2 | 67.3 | 67.2 | 64.6 | 59.9 | | | | | | |
| | | | 16.8 | 18.5 | 20.4 | 24.0 | 27.8 | | | | | | |
| | | | 63.4 | 66.0 | 66.3 | 64.1 | 59.2 | | | | | | |
| | | | 16.7 | 18.3 | 20.7 | 22.2 | 26.0 | 30.9 | | | | | |
| | | | 62.8 | 63.6 | 65.8 | 65.9 | 64.2 | 59.0 | | | | | |
| | | | 16.0 | 18.1 | 22.8 | 23.0 | 25.5 | 29.8 | 34.7 | 41.0 | 46.3 | 49.1 | 51.2 |
| | | | 63.4 | 65.4 | 68.1 | 70.0 | 64.6 | 60.8 | 55.4 | 53.4 | 52.6 | 43.3 | 39.7 |
| | | | 15.5 | 17.2 | 20.7 | 22.7 | 26.4 | 30.2 | 33.9 | 38.8 | 43.7 | 47.8 | 50.8 |
| | | | 68.2 | 71.2 | 70.3 | 65.8 | 63.3 | 59.3 | 57.4 | 56.9 | 54.8 | 49.2 | 45.6 |
| 10.9 | 14.5 | 14.7 | 11.7 | 13.5 | 18.1 | 21.4 | 24.8 | 29.1 | 33.1 | 38.5 | 44.2 | 49.3 | 53.5 |
| 69.7 | 70.4 | 64.9 | 67.9 | 70.9 | 68.7 | 66.0 | 65.9 | 56.6 | 56.3 | 59.1 | 52.8 | 47.3 | 48.7 |
| 9.29 | 15.6 | 13.8 | 15.0 | 13.7 | 19.0 | 22.5 | 25.4 | 30.4 | 33.2 | 40.0 | 46.9 | 54.7 | 57.1 |
| 70.0 | 62.6 | 55.6 | 58.0 | 63.1 | 63.1 | 61.9 | 57.2 | 54.0 | 52.2 | 53.8 | 49.9 | 45.5 | 46.6 |
| | | 20.1 | 14.7 | 11.8 | 16.9 | 24.5 | 26.7 | 31.4 | 34.5 | 41.7 | 47.6 | 49.3 | 57.4 |
| | | 55.9 | 55.7 | 65.5 | 68.9 | 67.0 | 56.7 | 53.6 | 52.6 | 49.9 | 47.0 | 46.0 | 45.7 |
| | | | | | | 20.7 | 22.0 | 25.4 | 35.0 | 39.7 | 44.5 | | |
| | | | | | | 67.1 | 59.5 | 57.1 | 52.8 | 50.2 | 48.4 | | |
| | | | | | | | 20.4 | 23.9 | 29.4 | 34.8 | | | |
| | | | | | | | 65.1 | 63.4 | 59.1 | 54.5 | | | |
| | | | | | | | 17.8 | 21.8 | 25.9 | | | | |
| | | | | | | | 64.7 | 61.2 | 61.8 | | | | |
| | | | | | | | | | 26.2 | | | | |
| | | | | | | | | | 60.7 | | | | |

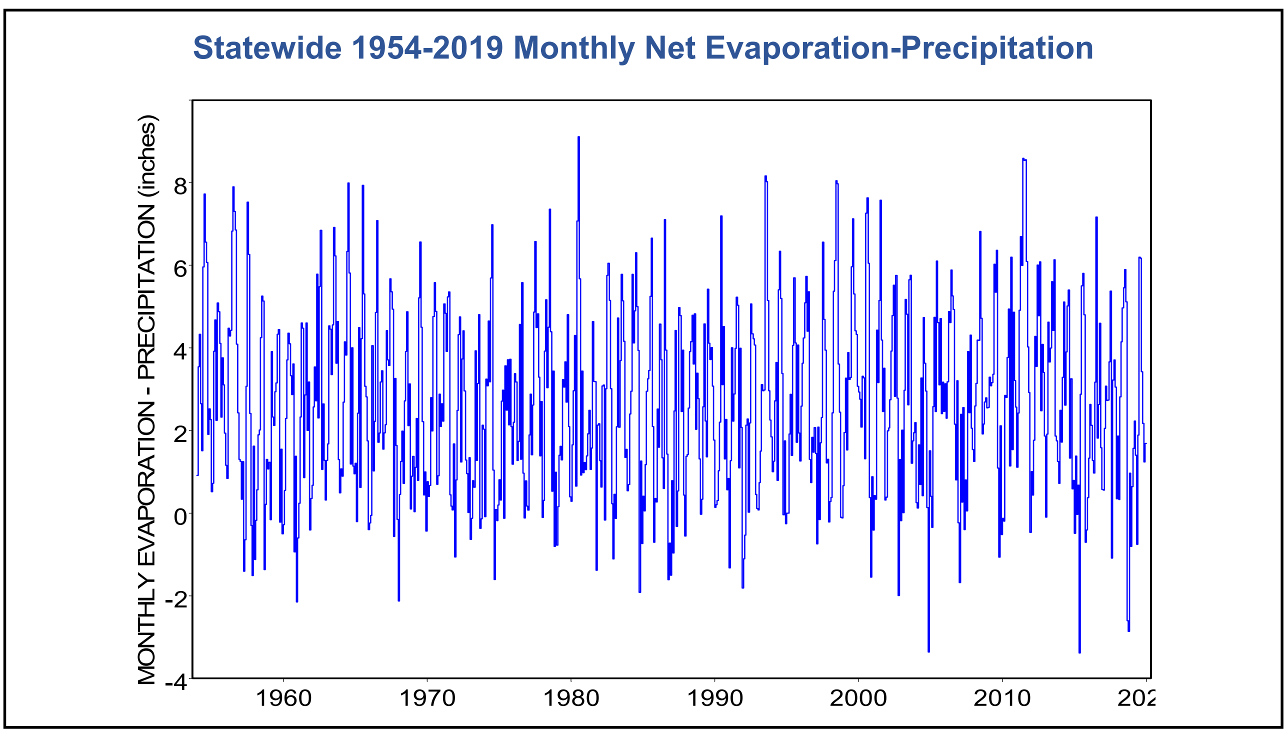
## Statewide 1940-2019 Monthly Precipitation (inches/month)

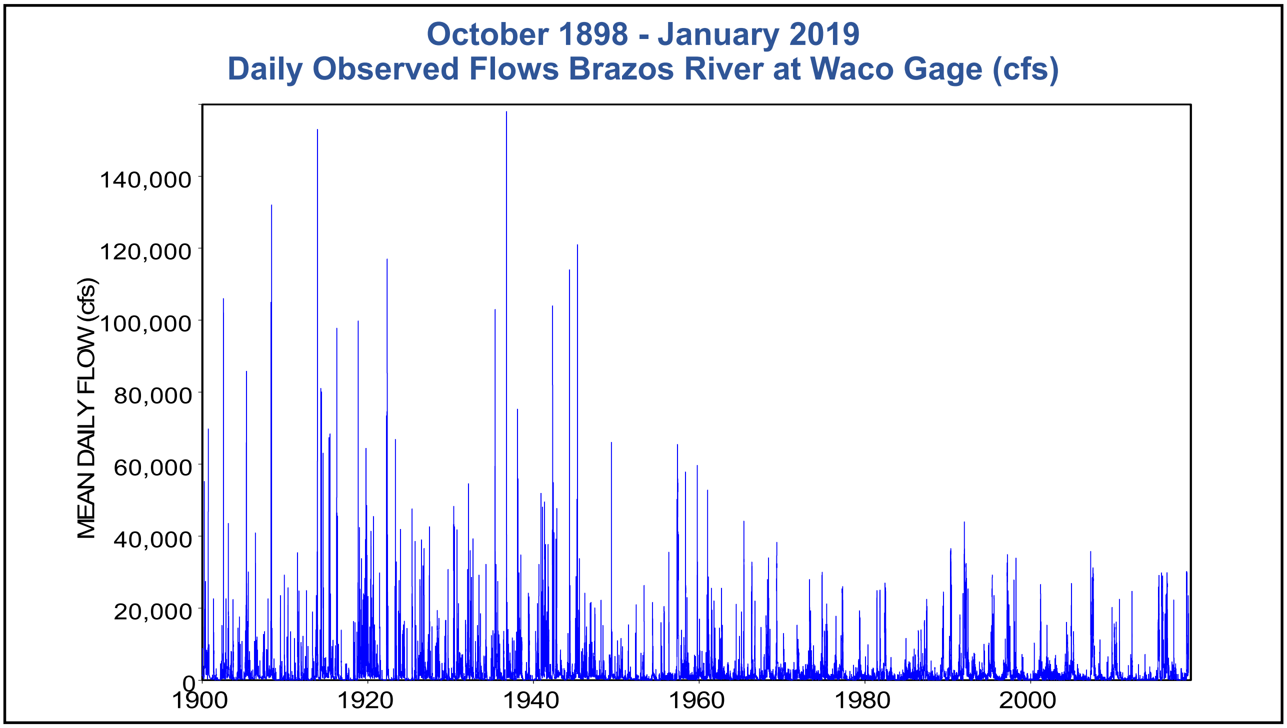


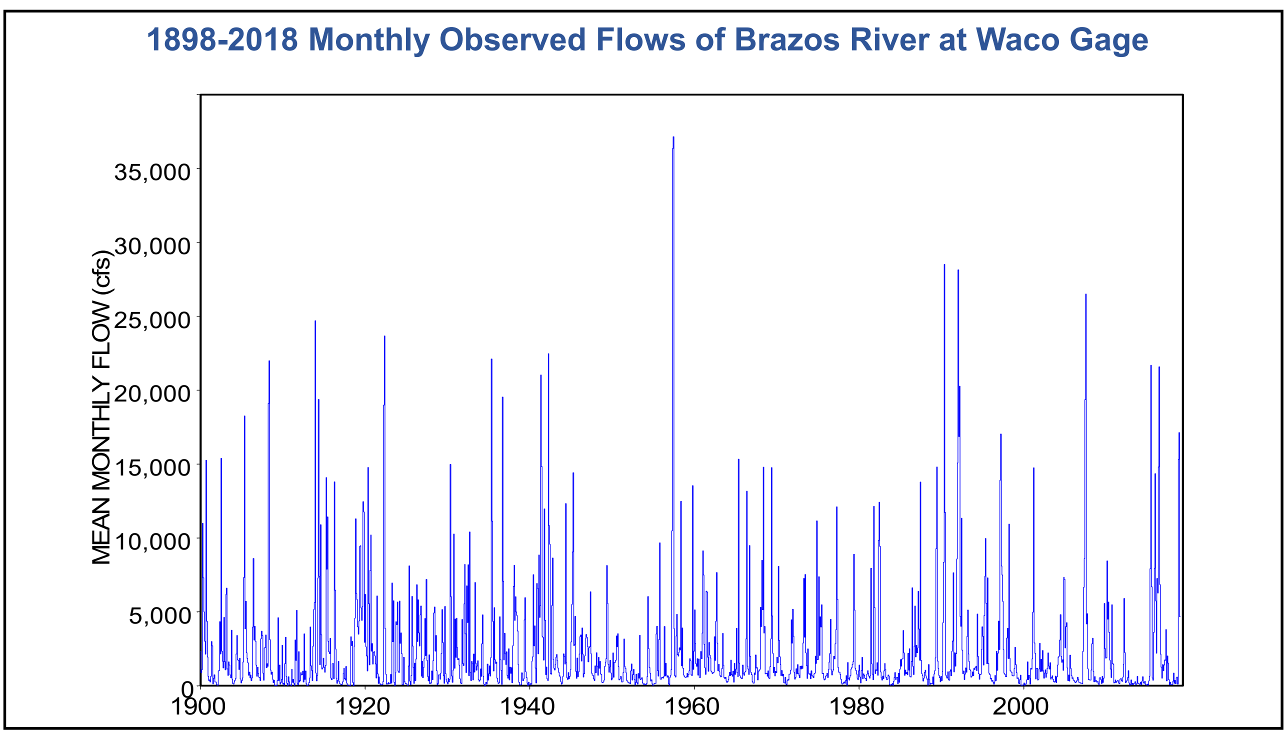

Statewide 1954-2019 Monthly Reservoir Evaporation (inches/month)
MONTHLY EVAPORATION DEPTH (inches)
0
2
4
6
8
10
1960
1970
1980
1990
2000
2010
202

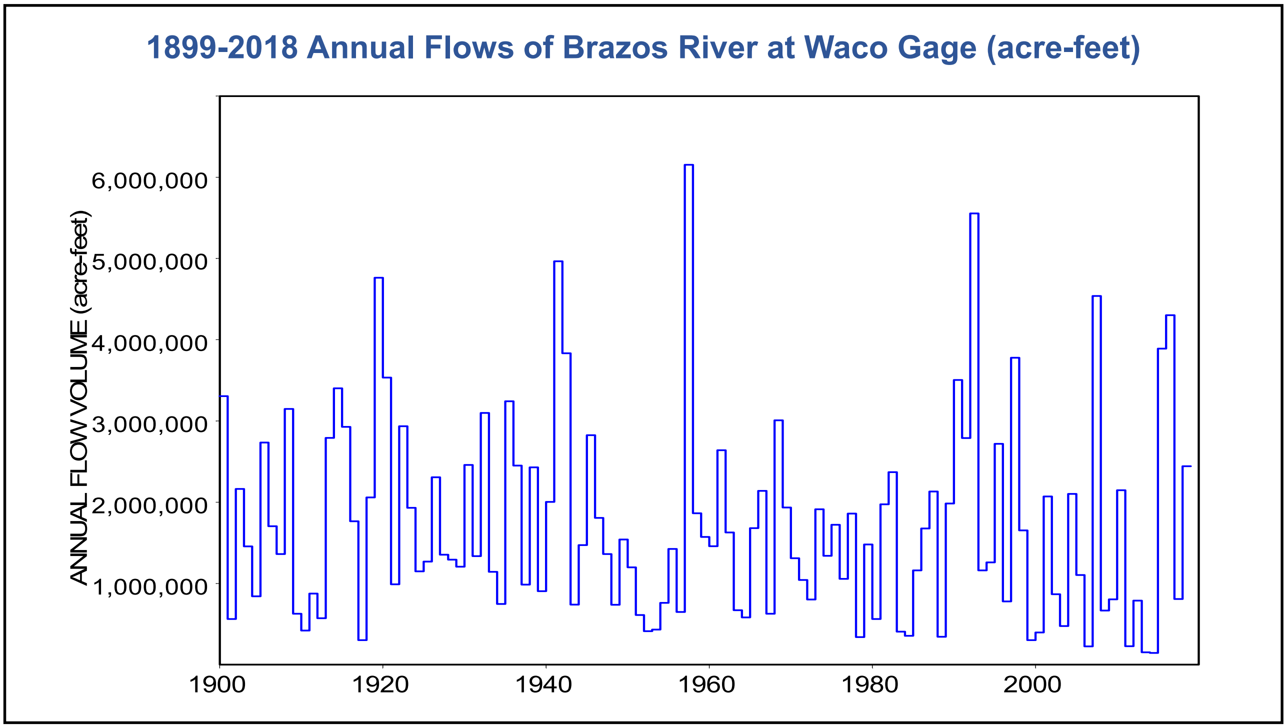

Statewide Annual Precipitation and Reservoir Evaporation (inches/year)
PRECIPITATION AND EVAPORATION (inches)
0
10
20
30
40
50
60
70
1940
1950
1960
1970
1980
1990
2000
2010
202

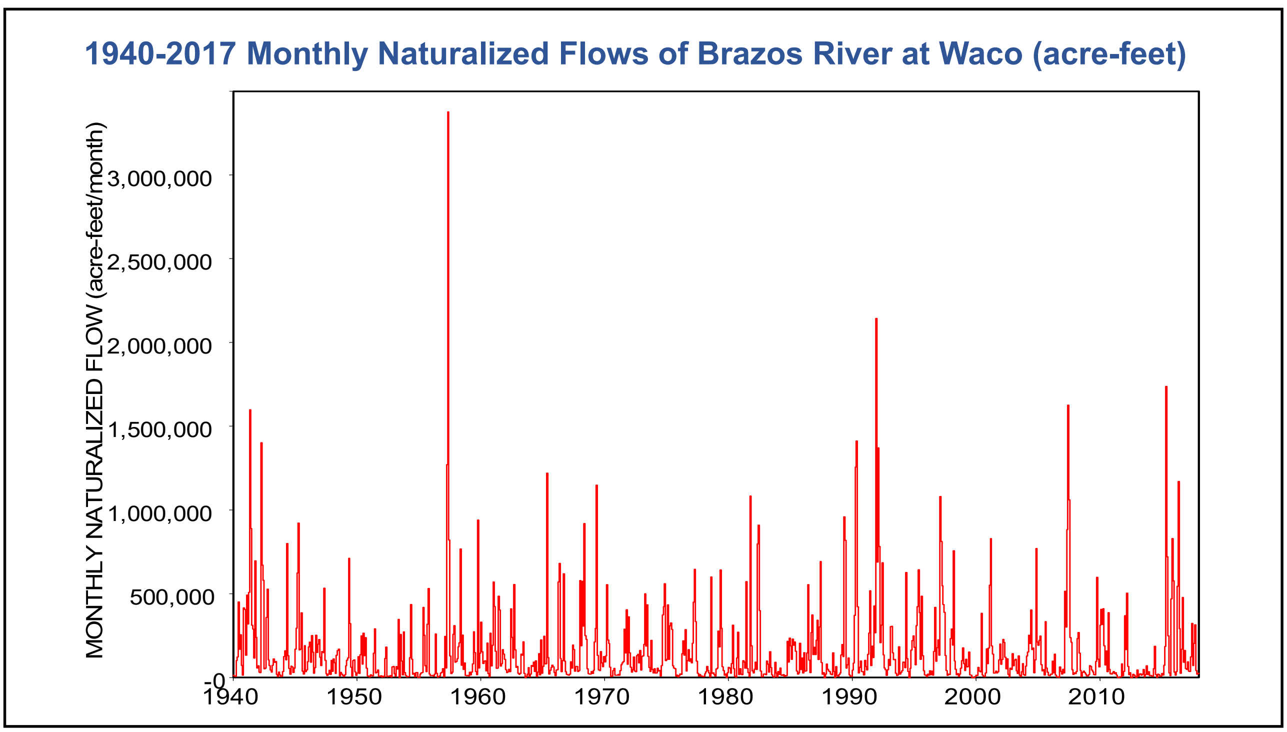

Statewide Average of Annual Maximum and Minimum Monthly
Precipitation and Reservoir Evaporation (inches/month)
PRCIPITATION AND EVAPORATION (inches)
0
2
4
6
8
10
1940
1950
1960
1970
1980
1990
2000
2010

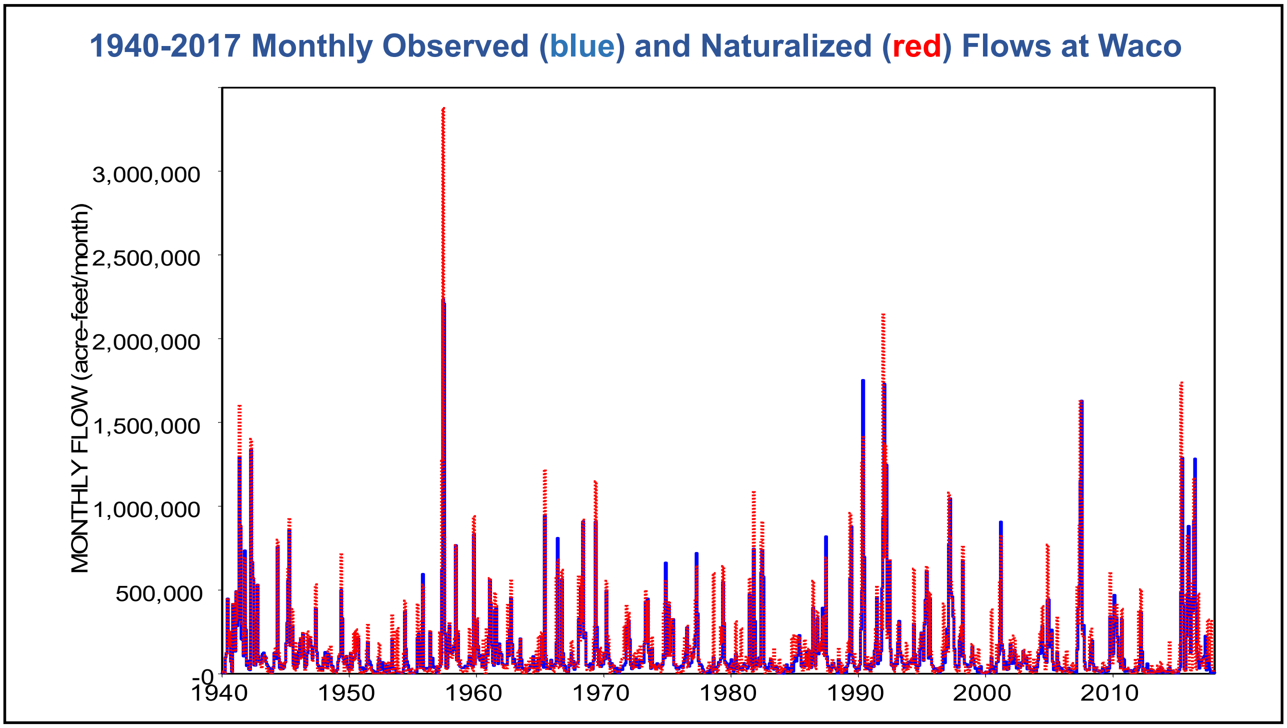

Statewide 1954-2019 Monthly Net Evaporation-Precipitation
MONTHLY EVAPORATION - PRECIPITATION (inches)
-4
-2
0
2
4
6
8
1960
1970
1980
1990
2000
2010
202


October 1898 - January 2019
Daily Observed Flows Brazos River at Waco Gage (cfs)
MEAN DAILY FLOW (cfs)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1900
1920
1940
1960
1980
2000

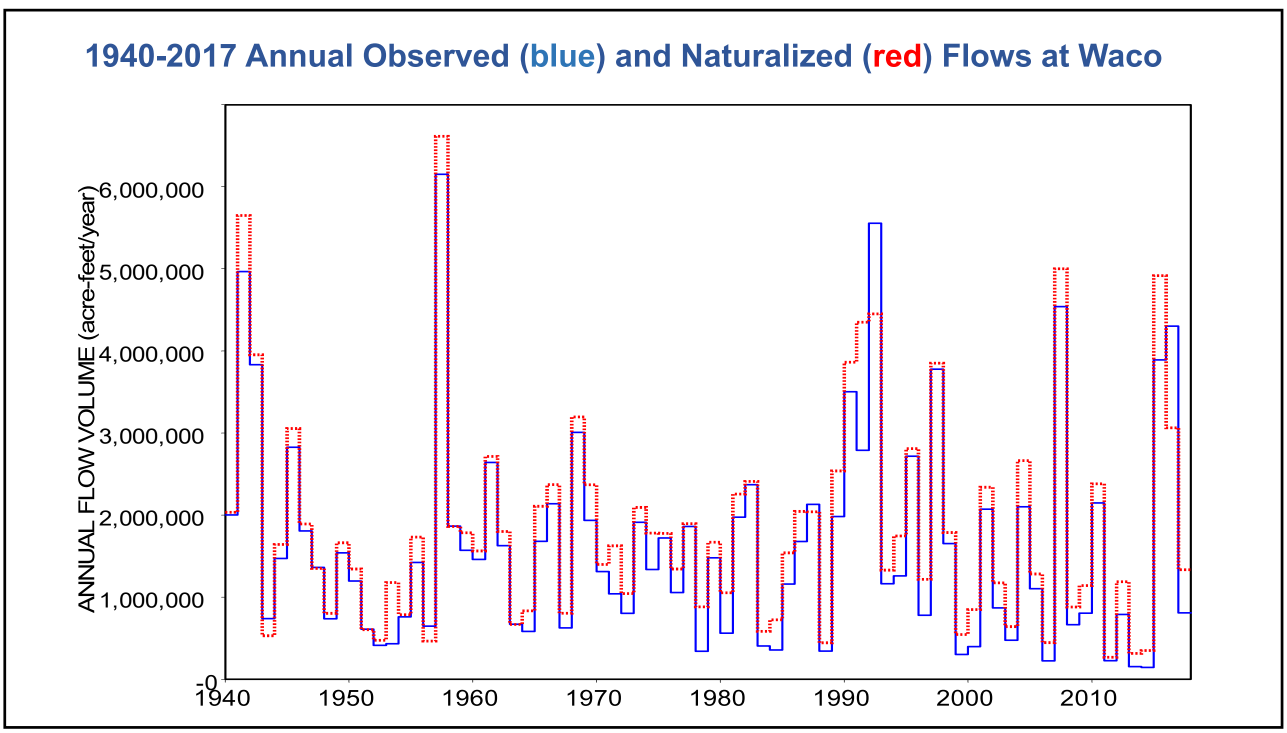

1898-2018 Monthly Observed Flows of Brazos River at Waco Gage
MEAN MONTHLY FLOW (cfs)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1900
1920
1940
1960
1980
2000


1899-2018 Annual Flows of Brazos River at Waco Gage (acre-feet)
ANNUAL FLOW VOLUME (acre-feet)
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
1900
1920
1940
1960
1980
2000


1940-2017 Monthly Naturalized Flows of Brazos River at Waco (acre-feet)
MONTHLY NATURALIZED FLOW (acre-feet/month)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1940
1950
1960
1970
1980
1990
2000
2010



1940-2017 Monthly Observed (blue) and Naturalized (red) Flows at Waco
MONTHLY FLOW (acre-feet/month)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
-0
1940
1950
1960
1970
1980
1990
2000
2010

1940-2017 Annual Observed (blue) and Naturalized (red) Flows at Waco
ANNUAL FLOW VOLUME (acre-feet/year)
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
-0
1940
1950
1960
1970
1980
1990
2000
2010

## Stream Flow Naturalization and Distribution

Naturalized flows at primary control points recorded on *IN* records in a FLO or DSS file are developed by adjusting gaged flows for upstream historical water development, management, and use.

- Reservoir construction and operation (all WAMs)
- Diversions and return flows (all WAMs)
- Land use changes (possibly)
- Pumping of aquifers which alter spring flows (some WAMs)

Naturalized flows at secondary control points are computed during the simulation based on flows at primary control points and parameters recorded in the flow distribution DIS file.

## Adjustments to Gaged Flows

naturalized flow = gaged flow
+ upstream diversions
− upstream return flows
+ change in upstream reservoir storage
+ upstream reservoir net evaporation-precipitation

## Channel Losses

- Channel losses represent the portion of the stream flow in the reach between two control points that is lost through seepage, evapotranspiration, and unauthorized diversions.
- Gaged flow records are the result of all upstream natural runoff and human activities, as well as the channel losses incurred as the water flows down the stream.
- Naturalizing gaged flows by adjusting for upstream human activities may include estimation of the channel losses associated with the effects of flow depletions, reservoir releases, and return flows propagating downstream.

## Incorporation of Channel Losses and Loss Credits in the SIM Simulation

Channel losses are considered in both (1) developing naturalized flows and (2) in the SIM simulation. Channel losses in a stream reach are defined as a linear function of flow at the upstream control point.

$$\text{Loss} = (CL_{factor})x(Q_{upstream})$$

Flow adjustments are computed using delivery factors.

$$\text{Deliver Factor} = (1.0 - CL_{factor})$$

(Reference Manual Chapter 3 Hydrology, pages 48-52)

## Constant Inflows

A consistent annual time series of positive or negative contributions to naturalized stream flow can be specified by inserting constant inflow *CI* records in the SIM DAT file.

A common use of *CI* records is to represent the return flow through municipal and industrial wastewater treatment plants or return flows from irrigation for water users supplied from groundwater.

## Time Series of Flow Adjustments

A time series of positive or negative adjustments to the naturalized flow can be applied using flow adjustment *FA* records in the SIM input.

Flow adjustment *FA* records have been used to model changes to spring flows or stream base flows associated with aquifer pumping or groundwater management scenarios.

## Ground–Surface Water Interactions

WRAP does not explicitly simulate groundwater and surface water interactions or directly link with a groundwater model.

Groundwater and surface water interactions can be implicitly modeled through *CP* record channel loss factors, *FA* record flow adjustments, or *CI* record return flows from groundwater supplies.

Return flows may represent water supplied from either surface or ground water sources.

## Secondary Control Points

SIM reads the *IN* records of monthly naturalized flows for all primary control points which typically represent sites of USGS stream flow gages.

SIM has several methods for distributing flows from primary (sites with *IN* records) to secondary (no *IN* records) control points, which are selected with the input variable *INMETHOD* on the *CP* records.

## Methods for Synthesizing Naturalized Flows (CP Record)

| | | | *Method for Obtaining Naturalized Flows* |
|---|---|---|---|
| INMETHOD (cp) | I8 | blank,0,1 | *IN* records are input for this control point. |
| | | 2 | Specifications are provided by *CPIN(cp)* in field 7. |
| | | 3 | Distribution equation with *FC* record coefficients. |
| | | 4 | NRCS CN method with synthesized flows limited to not exceed source control point flows |
| | | 5 | NRCS CN method without above noted flow limit |
| | | 6 | Channel loss coefficient with DAR method |
| | | 7 | Drainage area ratio method (areas from *WP* records) |
| | | 8 | NRCS CN method with channel losses |
| | | 9 | Control point flow does not limit available flow. |
| | | 10 | Equation proportioning flows at other control points. |
| CPIN(cp) | 2x,A6 | AN | Control point from which *IN* records are repeated. |
| | | NONE<br>ZERO | The words *none, zero, NONE, or ZERO* entered in this field indicate zero stream flows at this control point. |

## Flow Distribution Method 3

Regression equation using *FC* record coefficients

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

## Flow Distribution Methods 4 and 5

NRCS CN equation. Option 4 limits synthesized flows to not exceed source control point flows. Option 5 does not impose this upper limit.

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

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

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

## Flow Distribution Methods 6 and 7

Drainage Area Ratio (DAR) method with consideration of channel losses between the downstream gaged and upstream ungaged control points

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

$$R_{DA} = \frac{A_{ungaged}}{A_{gage}}$$

Method 7 uses the DAR method without channel losses.

**Method 8** incorporates channel losses in the option 5 adaptation of the NRCS CN method.

**Method 9** allows a control point to have no stream flow data without constraining water availability at other control points.

## Flow Distribution Method 10

Flows from other control points with established flows are multiplied by coefficients and added to flow at a gaged control point.

$$Q_{ungaged} = Q_{DSG} + (COEF1)\ Q1 + (COEF2)\ Q2 + (COEF3)\ Q3$$

## Available Flows

Available flows represent the amount of unappropriated stream flow available to a particular water right in the water right priority sequence in the simulation computations

Available stream flow is relevant to each individual water right and within the context of priority order. At the completion of the priority sequence, the available becomes the unappropriated flow.

## Unappropriated Flows

Unappropriated stream flows represent the monthly flow volumes still available at a control point for appropriation after considering all water right requirements.

Unappropriated stream flows are always less than or equal to regulated flows at the same control point.

Unappropriated flows may be less than regulated flows due to instream flow requirements or water allocations to senior downstream water rights.

## Regulated Flows

Regulated flows represent the actual physical stream flow at each control point location after accounting for all of the water rights.

Regulated flows are simulated monthly volumes that would be measured by a gage if the water resources development, management, allocation, and use scenario reflected in the SIM simulation DAT input file is combined with the historical natural hydrology reflected in the hydrology input dataset.

## Beginning Reservoir Storage Content

The default is to set all reservoirs full to the top of conservation storage capacity at the beginning of the SIM simulation.

The user can alternatively specify the beginning-of-simulation storage contents of reservoirs on the WS record or by use of a beginning reservoir storage BRS input file.

The beginning-ending storage (BES record) options are based on setting the beginning-of-simulation reservoir storage contents equal to end-of-simulation reservoir storage contents.

## Basics of Water Availability Modeling with the Water Rights Analysis Package (WRAP)

## Module 5 – Simulation of Water Management

Presented by Ralph Wurbs, Ph.D., P.E.
Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the
Texas Commission on Environmental Quality

## Seven Modules of Course on Basics of Water Availability Modeling with WRAP

1. Overview of WRAP/WAM Modeling System
2. WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records
3. Executing Programs and Managing Files and Records
4. Hydrology Features of the Modeling System
5. **Simulation of Water Management (this module)**
6. Simulation Model Computational Algorithms
7. Supply Reliability, Flow and Storage Frequency, and Other Analyses of Simulation Results

## WRAP Program SIM Simulation Model

Water resources development, management, allocation and use are modeled in SIM as water rights associated with water right WR or instream flow IF records.

- reservoirs, pumping plants, conveyance facilities, return flows, hydroelectric plants
- international treaties, interstate compacts
- requirements specified in water right permits
- reservoir system operating rules
- requirements for preservation of instream flows

## Information Provided on Water Right (WR) or Instream Flow (IF) Record and Supporting ES, HC, WS, OR, UC, HP, SO, UP, RF, DI, EA, ML, MS, BU, FS, CV, PX, and TS Records

(Reference Manual Chapter 4 and Users Manual Chapter 3)

- Control point location
- Annual demand volume in acre-feet/year
- Monthly demand distribution pattern
- Options for varying the monthly demand target
- Reservoir storage capacity and operating rules
- Priority (typically but not necessarily representing a priority date)
- Return flow specifications for WR record rights

## Information on WR and UC Records

(Example from Fundamentals Manual, pages 57-58, 86, 83)

```
**  Cameron Gage - Run-of-River Diversion Rights  *****!*******!******
**
WR Camer  92100.    IRR2  198211       2    0.35                WR-12
WR Camer  18200.    IND2  196105       2    0.50                WR-13
WR Camer  11300.    IRR2  194510       2    0.10                WR-14
**
```

```
**  Water Use Coefficient (UC) Records
**
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  IRR1   0.005   0.007   0.017   0.033   0.092   0.163   0.267   0.235   0.117   0.044   0.014   0.007
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.
**
```

## Water Right Priorities

- Available stream flow is allocated to each water right in turn in ranked priority order.
- Priority numbers (often but not necessarily always dates) establish a relative ranking for sequencing each access to available stream flow for each water right in the simulation computations.
- The terms *"junior"* and *"senior"* refer to the relative priority of two or more water rights.

## Adjustments to Water Right Priorities

- If two or more water rights have the same priority number on their WR or IF records, they are ranked in the relative order that their WR or IF records are entered in the DAT input file. The right read first from the DAT file is assigned the higher priority of the two rights.
- Various options for modifying priorities are controlled by priority circumvention PX or water use group priority modification UP records.

## WR Record Water Right Types

(Fundamentals Manual, page 86)

Type 1 – Access first to stream flow and then to reservoir storage.
Reservoir storage refilling after meeting the diversion target.

Type 2 – Same as Type 1, except that no storage refilling is allowed.

Type 3 – Only releases from reservoir storage; no stream flow depletions and no refilling storage.

Type 4 – Inflow discharged to the river system.

Type 5 – Hydropower equivalent of Type 1.

Type 6 – Hydropower equivalent of Type 3.

Type 7 – Sets reservoir storage capacity (storage target).

Type 8 – Target computed for use with FS and TO records.

## Water Right Targets
## (Representing Demands, Needs, or Authorized Amounts)

WR record diversion targets (water right types 1, 2, 3), hydroelectric energy targets (types 5 and 6), discharge targets (type 4), storage targets (type 7), or TO/FS record targets (type 8).

IF record minimum instream flow targets.

## Options for Setting WR and IF Record Targets

- Constant annual volume and monthly distribution (water use coefficient *UC* records)
- Targets as a function of stream flow (target options *TO*, flow switch *FS,* cumulative volume *CV* records)
- Drought index to vary target with reservoir storage (drought index *DI*, index storage *IS*, and percentage *IP* records)
- Environmental flow standards (environmental standard *ES*, hydrologic condition *HC*, and pulse flow *PF* records)
- Predetermined targets (target series *TS* records)

## Options Associated with Strategies for Meeting Targets

- Monthly, seasonal, or annual limits on diversions, stream flow depletions or withdrawals from storage (supplemental options *SO* record)
- Stream flow depletions from alternate locations (supplemental options *SO* record)
- Secondary backup right that supplies shortages incurred by other rights (backup *BU* record)
- Diversions or releases from reservoir storage (water right storage *WS* record)

## Hydroelectric Energy Generation

- WR record type 5 and type 6 water rights generate hydroelectric energy. Monthly hydroelectric energy generation targets in megawatt-hours are set similarly to monthly water supply diversion targets in acre-feet.
- A hydropower HP record for a WR record water right provides input regarding hydraulic-to-electric efficiency, tailwater elevation, turbine invert elevation and discharge capacity, and maximum limit on secondary energy generation.

## Return Flows in the SIM Simulation

- Return flows can be portions of withdrawals from surface (WR record) or ground (CI record) water sources discharged to a stream after use.
  - municipal/industrial wastewater treatment effluent
  - irrigation returns
- Return flows can also represent water transported through pipelines or canals.
- Releases through hydroelectric power turbines are also treated computationally as return flows.

## Location of Return Flows

- The default WR record RFMETH(wr) option is to discharge return flows at the next downstream control point.
- Any downstream or upstream control point can be specified as RCP on the WR record, even in another river basin within the simulation model.

## Timing of Return Flows

(WR Record RFMETH Options)

Option 1 – The default option is to discharge the return flows in the same month as the diversion.

Option 2 - Return flows can also be discharged in the next month of the simulation at the beginning of the priority sequence allowing senior water rights access to the return flows.

## Return Flow as Percentage of Diversion

Return Flow = Factor x Diversion Amount

- A constant return flow factor entered on the WR record can be used for all months.
- Return flow factors can be specified for each of the 12 months of the year on RF records.

## Examples of Water Rights

(Fundamentals Manual pages 58, 86, 88)

```
**  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.
**
```

## Instream Flow Requirements

- Instream flow requirements are activated by IF records and are called IF record water rights.
- The IF record water right sets a target minimum regulated flow at a control point.
- The same target setting options for WR records can be used for IF records.
- Environmental standard ES, hydrologic condition HC, and pulse flow PF records are used with IF records to model SB3 environmental flow standard format.
- Stream flow availability for junior WR record water rights are constrained by the minimum regulated flow targets set by senior IF record water rights.

## Multiple IF Record Rights at the Same Control Point

- Multiple IF rights can be located at the same control point.
- Each IF record may specify a different regulated flow target at a different priority.
- The default for IF record parameter IFM(if,2) is for the most junior IF record to replace the preceding IF record targets.
- IFM(if,2) options 2 and 3 adopt the largest or smallest target for that IF record considered at that control point in the water rights priority sequence.

## Other IF Record Instream Flow Options

Like WR record rights, IF record rights can call for upstream reservoir releases to meet their targets.

IF records can be met with the total regulated flow at the control point, or reservoir releases for other water rights can be excluded.

## IF Records in the Fundamentals Manual Example

(FM Appendix A, page 57; Appendix C, page 88)

```
** Instream Flow Requirements at Cameron and Hempstead Gages
**
IF Camer   3600.   NDAYS      0                IF-1
IF  Hemp 120000.   NDAYS      0                IF-2
**
```

## Reservoirs

- WR record rights refill reservoir storage and divert or release water from reservoirs. Releases can also be used to supply IF record instream flow requirements. Only WR record type 1 rights or IF record rights can refill reservoir storage.
- Each reservoir is associated with at least one WR or IF record and only one CP record.
- Multiple WR and IF records with different priorities can have access to the same reservoir.
- Total storage capacity and inactive storage capacity from WS records may vary between water rights at the same reservoir.
- Multiple reservoirs may be assigned to the same control point.

## Input Parameters Specified on WS Record
## Reservoir Storage Associated with a Water Right
(Fundamentals Manual, pages 89-90)

RES – reservoir identifier

WRSYS- total storage capacity at top of conservation

A, B, and C for area = A(storage)$^B$+C

Default is SV/SA record storage/area table

INACT – storage capacity at top of inactive pool

BEGIN – beginning storage with default of capacity

IEAR, SA – evaporation allocation EA record option

LAKESD – whether water supply diversions are
or discharged through hydropower turbines

## Example of a WR/WS Records
(FM Appendix A, page 58; Appendix C, pages 86-92)

```
** 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                  990000                                   WR-5            Refill
WS  Whit 627100.                         379000


SV  Whit      0.      9.   1145.   4843.  51240. 157245. 379108. 427400. 559219. 627100. 807330. 1120975
SA            0.     22.    237.    507.   3210.   7500.  15760.  16450.  21740.  23560.  28070.  34920.
**
PV  Whit   2630.  19600.  41710.  79990. 143200. 229400. 363600. 473100. 601800. 782000. 1095000 1473000
PE         448.8   470.0   480.0   490.0   500.0   510.0   520.0   527.0   533.0   540.0   550.0   560.0
```

## System Operations

- Run-of-river rights
- Reservoir storage
- Water right types
- Primary and secondary reservoirs
- Multiple reservoir system operations
- Off-channel storage
- Multiple-owner reservoirs
- Backup rights

## Primary and Secondary Reservoirs

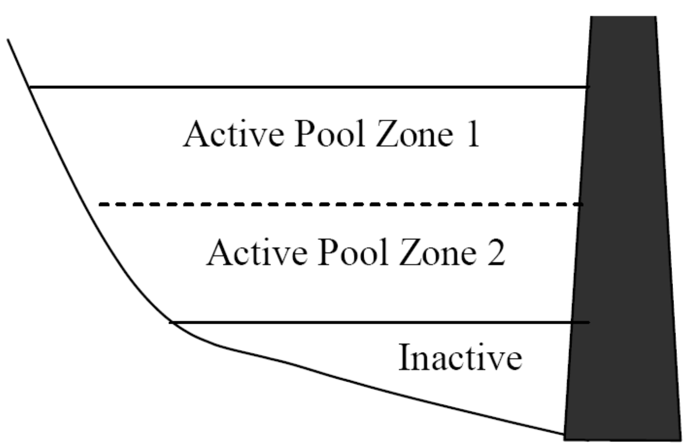
- A water right can be associated with any number of reservoirs.
- Storage is refilled in reservoirs only by a WR record type 1 water right or IF record right. A single water right can refill storage in only one reservoir (called the primary reservoir) but can divert or release water from any number of secondary reservoirs.
- The WR record type 1 water right and its primary reservoir must be located at the same control point.
- WR record types 2 and 3 rights can only divert or release from reservoirs. Only WR record type 1 rights can not refill storage.

## Example of Type 2 Water Right Supplied by Secondary Reservoirs

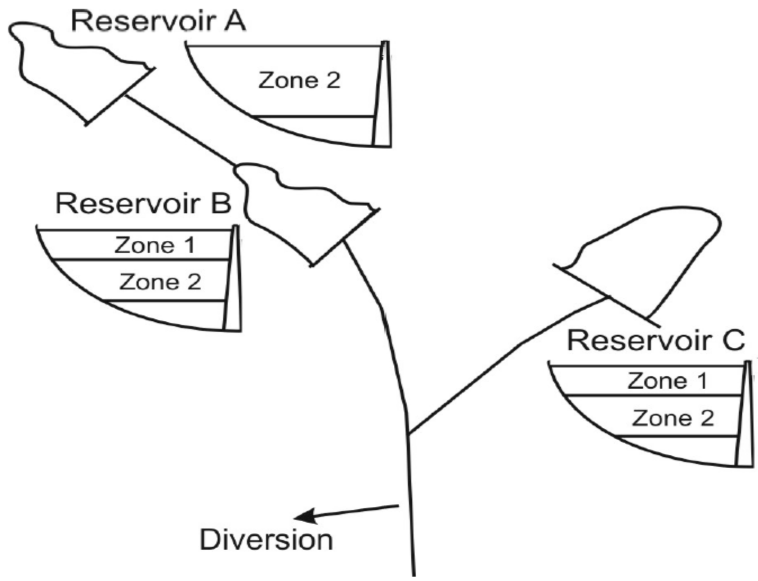
(Fundamentals Manual, pages 59, 86, 89)

```
**  Hempstead Gage - Multiple-Reservoir System Diversion Right  *******!*******!*******!
**
WR  Hemp 475000.    MUN2  201901   2                              WR-24          SystemH
WS    PK 570240.
WSBelton 457600.
WSGeorge  37100.
WS Grang  65500.
**
**  Refilling Storage in Multiple-Reservoir System Reservoirs  !*******!*******!*******!
**
WR    PK                  990000                              WR-25          Refill
WS    PK 570240.
WRBelton                  990000                              WR-26          Refill
WSBelton 457600.
WRGeorge                  990000                              WR-27          Refill
WSGeorge  37100.
WR Grang                  990000                              WR-28          Refill
WS Grang  65500.
```

## Zones Defined By Operation Rules OR Record for Multiple-Reservoir System Operations



## OR Record Zones in System Reservoirs




## Rank Index for Multiple-Reservoir System Operations

The operating rules *OR* record includes an input multiplier factor (*M*) used in the simulation to compute a rank index used to determine the reservoir from which to release in each time period.

$$Rank\ Index = M \left[\frac{storage\ content\ in\ zone}{storage\ capacity\ of\ zone}\right]$$

## Multiple Rights for Water Supplied from the Same Reservoir

The last two topics covered in this course module deal with two different complexities of modeling multiple water rights that share the same reservoir.

1. The evaporation allocation EA record provides options for allocating reservoir net evaporation-precipitation to component computational reservoirs used to model multiple water rights that share the same reservoir.
2. The dual simulation option controlled by the PX record input parameter DUAL deals with the issue of senior rights refilling storage depleted by junior rights.

## Allocation of Evaporation-Precipitation Volume between Computational Component Reservoirs

(EA and EF Records, Users Manual, pages 117-119)

The EA record provides the following alternative methods for allocating evaporation-precipitation volume between component reservoirs used to model multiple water rights sharing the same single actual reservoir.

1. Incremental based on water right priorities.
2. Based on beginning-of-month storage content.
3. Based on factors input on EF records.
4. Combination of options 1 and 3.

## Dual Simulation Option

(Input Parameters DUALD (default) and DUAL (individual rights) on PX and JO Records)

The dual option performs the simulation twice with user-specified water rights included or excluded in each of the two simulations. Streamflow depletions computed in the first simulation are employed as maximum limits on streamflow depletions during the second simulation. The main reason for the dual option is to prevent junior rights from diverting water from storage refilled by senior rights at the same reservoir.

## Waco Reservoir in Fundamentals Manual Example

(Appendix A, Page 58; Appendix C, pages 86, 89)

```
** 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.
**
```

## Basics of Water Availability Modeling with the Water Rights Analysis Package (WRAP)

## Module 6 - Simulation Model Computational Algorithms

Presented by Ralph Wurbs, Ph.D., P.E.
Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the
Texas Commission on Environmental Quality

**Seven Modules of Course on Basics of Water Availability Modeling with WRAP**

1. Overview of WRAP/WAM Modeling System
2. WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records
3. Executing Programs and Managing Files and Records
4. Hydrology Features of the Modeling System
5. Simulation of Water Management
6. **Simulation Model Computational Algorithms (this module)**
7. Supply Reliability, Flow and Storage Frequency, and Other Analyses of Simulation Results

## Simulation of Water Rights in the WRAP Simulation Model SIM

- SIM simulates water resources development, management, allocation, and use (water rights) during an assumed repetition of historical natural river system hydrology.
- In WRAP terminology, a model "*water right*" is a set of water management and use requirements and the constructed facilities and institutional mechanisms for achieving those requirements.

## Iterative Water Accounting Algorithms

Computation of Net Evaporation-Precipitation (EP) Volumes

EP volume = (average reservoir surface area) x EP depth

Average reservoir surface area in acres is a function of beginning-of-month and end-of-month storage volumes. End-of-month storage volume is a function of EP volume.

Hydroelectric Energy Generation

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

Energy E (megawatt-hours), discharge Q (acre-feet/month), head H (feet), efficiency (dimensionless), time t (month), unit weight γ (62.4 lb/$ft^3$), and conversion factors (0.0010237).
H depends upon Q which depends upon H.
[Reference Manual page 99]

## SIM Warning Messages Related to Computation of Net Evaporation-Precipitation Volumes

WARNING: Reservoir storage and evaporation computations did not converge to within stop criteria in 50 iterations for water right 60804261005

Reservoir: LIVSTN; CP: B4248B; Year: 1967; Month:10; Final Evap:10813.06

Begin Storage:1528739.88; 49th End Storage:1530421.00; 50th End Storage adopted:1530420.88

WARNING: Evaporation volume has wrong sign. 1975 2 BENBR4

Volume = -12.6 depth = 0.010

## Linear Interpolation of Tables

Storage Volume (SV) versus Surface Area (SA)
Storage Volume (PV) versus Elevation (PE)
Tailwater Discharge (TQ) versus Elevation (TE)
Drought Index Storage (IS) versus Percentage (IP)

## Interpolation Exceeds Range Covered by Table

Error Message if ICHECK =1
Warning Message if ICHECK=9
[Reference Manual Chapter 9, pages 345 and 347]

WARNING: Interpolation routine exceeded range of table 2
max X = 0.00 given X = 65530.500 Y = max Y = 0.0
Year: 1940 Month: 2 Water Right: GRNGER-FRREL

ERROR: Program terminated because interpolation exceeded table maximum by more than 1.0 percent.
Table: 2 max X = 0.00 given X = 65530.500 Y = max Y = 0.0
Year: 1940 Month: 2 Water Right: GRNGER-FRREL
The following array was unsuccessfully interpolated.

- Main input file containing water rights data is read.
- Water rights are ranked in priority order.
- Various other data manipulations are performed.
- Flow distribution file containing watershed parameters is read.
- Watershed parameters are determined for incremental watersheds.

***Annual and Monthly Simulation Loop***

* Naturalized flow and net evaporation rates are read or activated.
* Naturalized flows are transferred from gaged to ungaged sites.

***Water Right Priority Loop***

1. Diversion, instream flow, or hydropower target is set.
2. Water availability is determined from available flow array.
3. Operating decisions and water balance in an iterative loop.
4. Available stream flow array is adjusted for effects of right.
5. Simulation results for this water right are recorded.

* Simulation results for control points are recorded.
* Simulation results for reservoirs/hydropower projects are recorded.

Figure 3.1 Outline of Simulation Performed by *SIM*
Fundamentals Manual page 20

## SIM Priority Loop Computations for Each Water Right in a Given Month

- Target is set.
- Water availability is checked.
- Water is allocated to meet target.
- Available stream flow array is adjusted.
- Results are recorded in output file.

## Diversion, instream flow, or hydropower target is set.

- Annual target from water right *WR* record (page 86) or *IF* record (page 88) combined with 12 monthly distribution factors from *UC* record (page 83 of Fundamentals Manual).
- Target options *TO* record in Users Manual.
- Drought index from *DI* record.
- Backup right *BU* record in Users Manual.
- Flow switch *FS* record in Users Manual.
- Target series *TS* record in Users Manual.
- Environmental flow standard *ES* record.

## Water availability is checked.

The volume of water available to the water right is the minimum flow volume in the CPFLOW array at that control point and all downstream control points.

## Water is allocated to meet target.

- Water right type and return flow specifications from WR record (page 86).
- Reservoir storage from WS record (page 89) and storage-area SV/SA records (page 92).
- Operating rules OR record in Users Manual.
- Monthly storage capacity on MS records.
- Hydropower HP record (page 91) and storage-elevation records in Users Manual.
- Target options TO record.
- Supplemental options SO record.
- Other auxiliary records defining water rights.

## Available stream flow array is adjusted.

The CPFLOW array is adjusted at the control point of the water right and at all downstream control points.

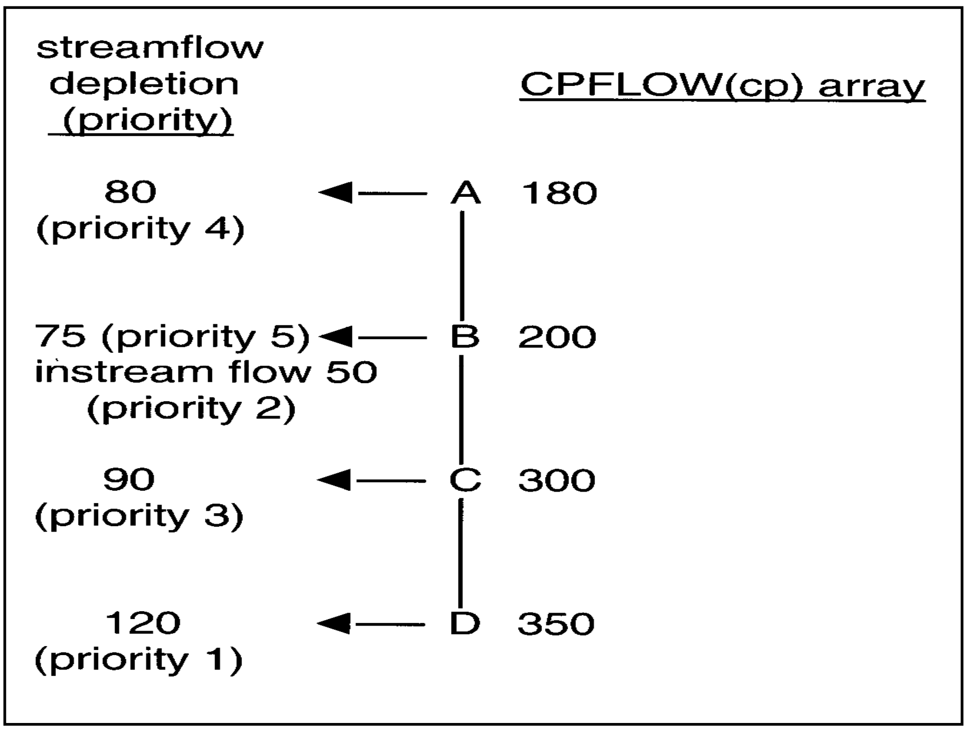
## Stream Flow Terms

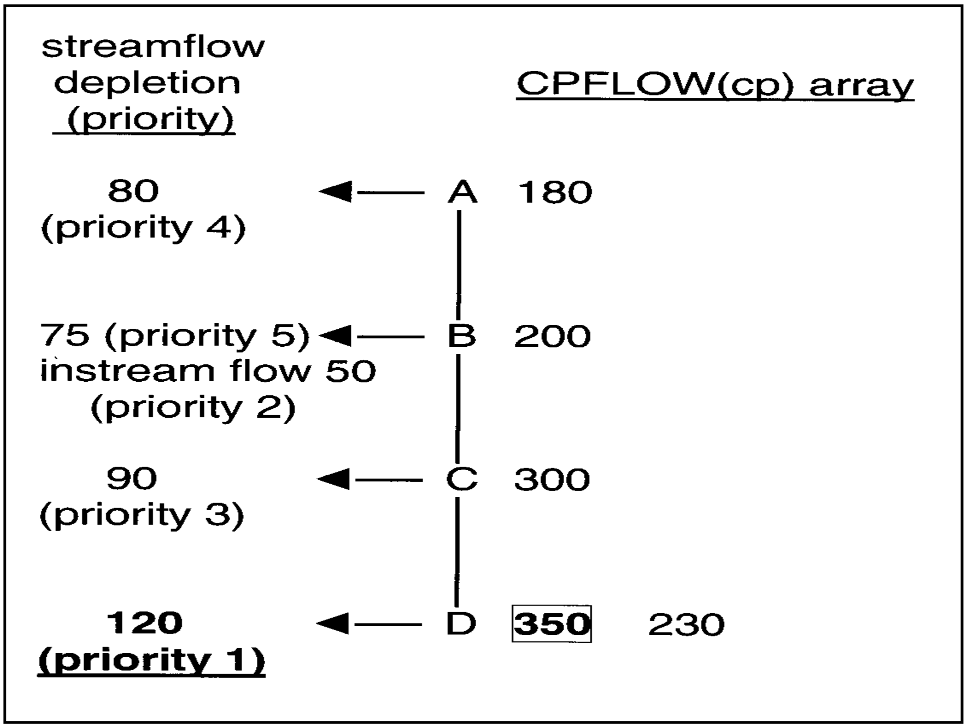
- Naturalized Flows
- Regulated Flows
- Unappropriated Flows
- Available Flows
- Stream Flow Depletions

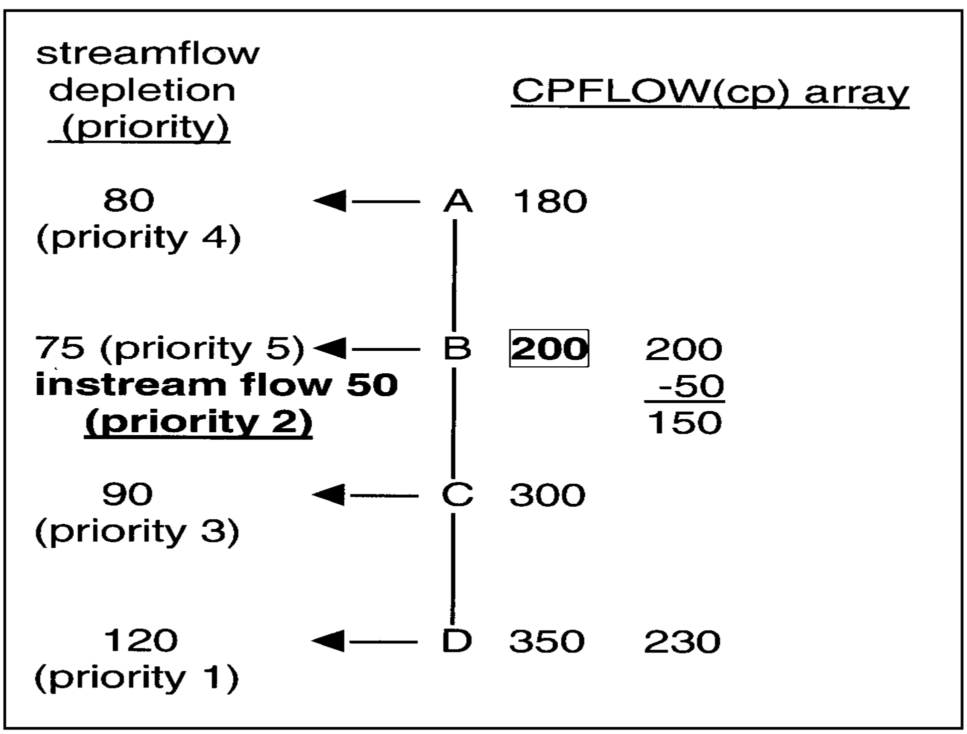
Example of WRAP-SIM Simulation Computation of Regulated Flow and Unappropriated Flow in Water Rights Priority Sequence for One Month of a Simulation

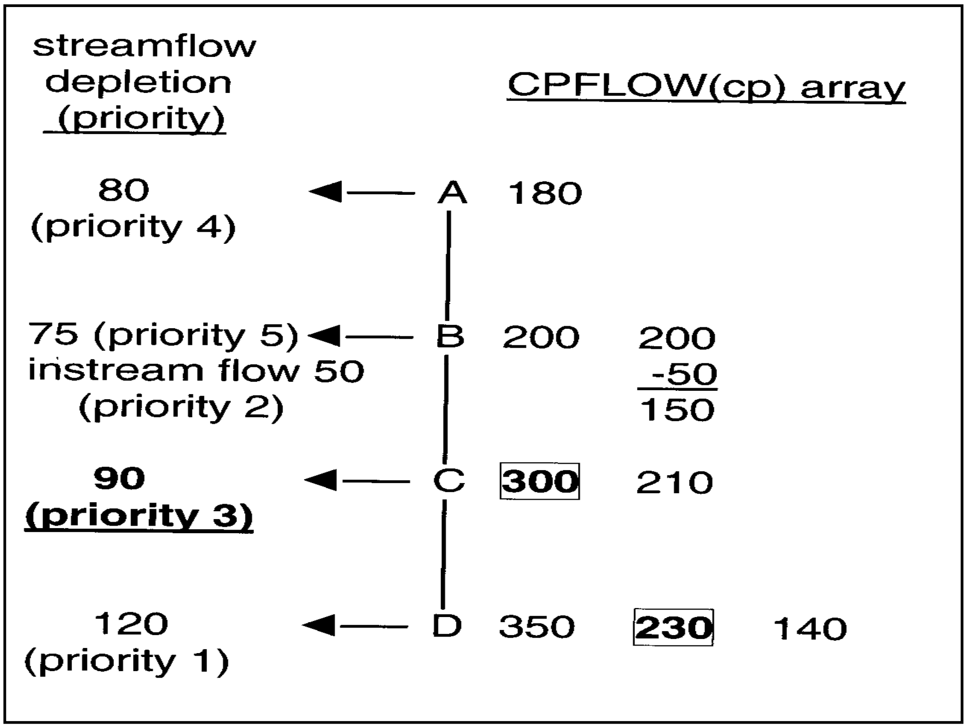
| CP | Naturalized Flow (ac-ft/month) | Depletion Target (ac-ft/mon) | Regulated Flow (ac-ft/month) | Unapprop Flow (ac-ft/mon) |
|---|---|---|---|---|
| A | 180 | 80 | ? | ? |
| B | 200 | 75 | ? | ? |
| C | 300 | 90 | ? | ? |
| D | 350 | 120 | ? | ? |

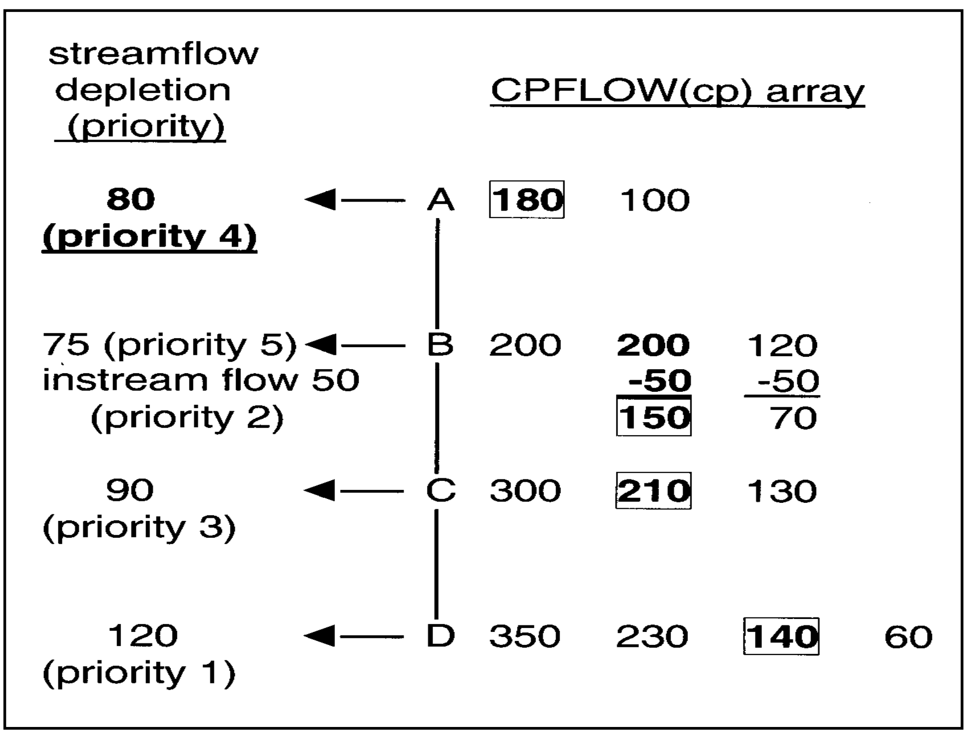
Instream flow target of 50 at control point B.

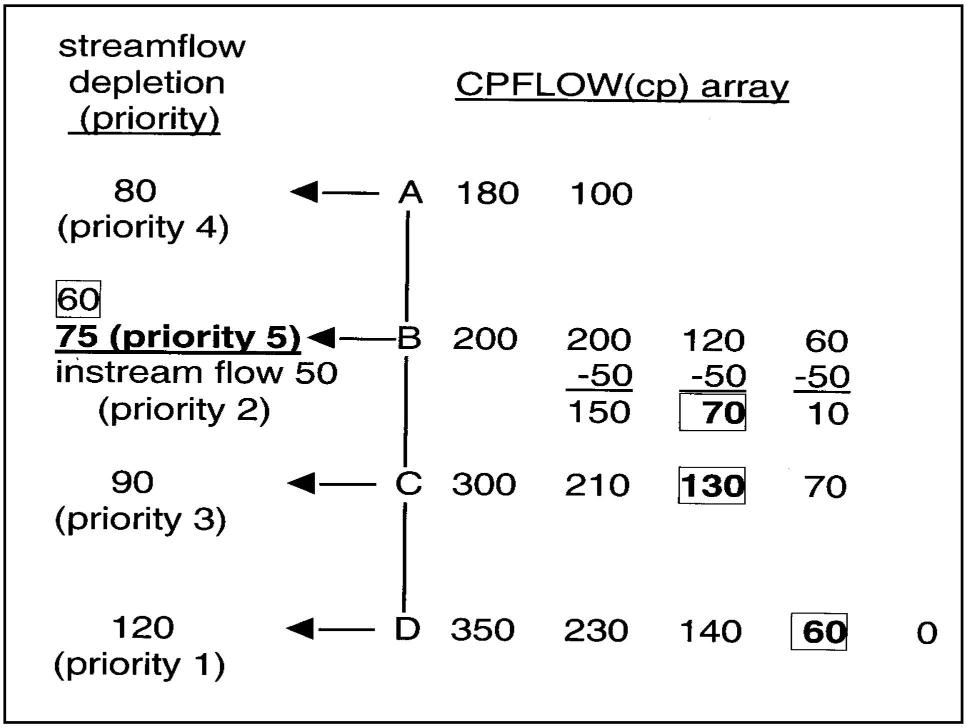


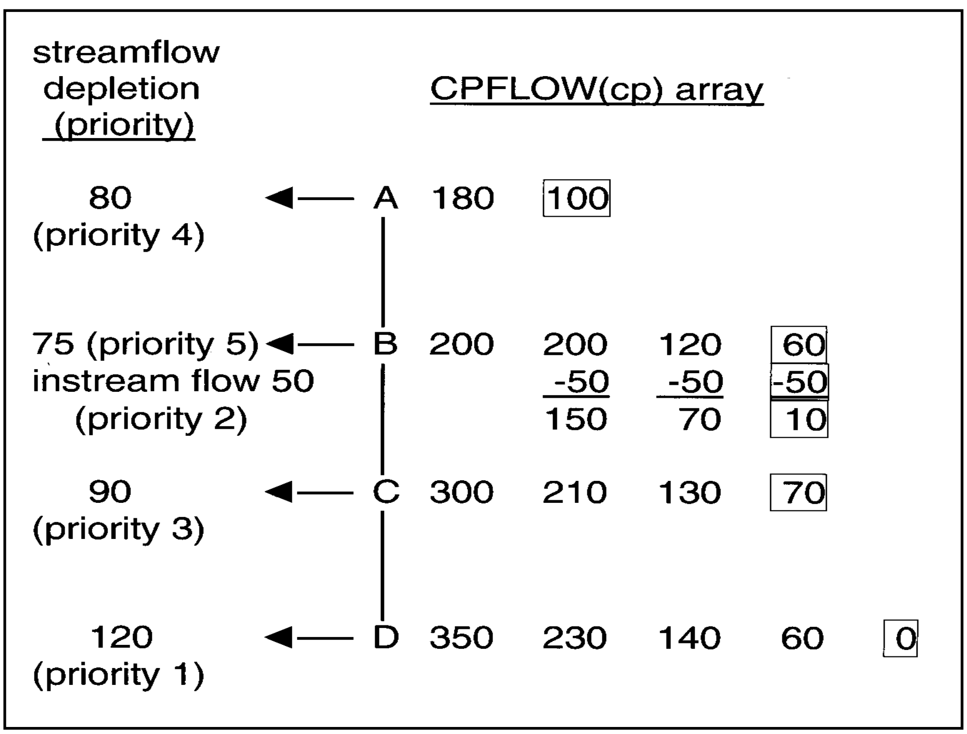

streamflow
depletion
(priority)
CPFLOW(cp) array
80
(priority 4)
A
180
75 (priority 5)
instream flow 50
(priority 2)
B
200
90
(priority 3)
C
300
120
(priority 1)
D
350
230


streamflow
depletion
(priority)
CPFLOW(cp) array
80
(priority 4)
A
180
75 (priority 5)
instream flow 50
(priority 2)
B
200
200
-50
150
90
(priority 3)
C
300
120
(priority 1)
D
350
230


streamflow depletion (priority)
CPFLOW(cp) array
80 (priority 4)
A 180
75 (priority 5)
instream flow 50 (priority 2)
B 200 200 -50 150
90 (priority 3)
C 300 210
120 (priority 1)
D 350 230 140


streamflow depletion (priority)
CPFLOW(cp) array
80 (priority 4)
A 180 100
75 (priority 5)
instream flow 50 (priority 2)
B 200 200 -50 150 120 -50 70
90 (priority 3)
C 300 210 130
120 (priority 1)
D 350 230 140 60


streamflow
depletion
(priority)
CPFLOW(cp) array
80
(priority 4)
A 180 100
60
75 (priority 5)
instream flow 50
(priority 2)
B 200 200 120 60
-50 -50 -50
150 70 10
90
(priority 3)
C 300 210 130 70
120
(priority 1)
D 350 230 140 60 0


streamflow
depletion
(priority)
CPFLOW(cp) array
80
(priority 4)
A 180 100
75 (priority 5)
instream flow 50
(priority 2)
B 200 200 120 60
-50 -50 -50
150 70 10
90
(priority 3)
C 300 210 130 70
120
(priority 1)
D 350 230 140 60 0

## Final Simulation Results for the Month

| CP | Naturalized Flow (ac-ft/month) | Flow Depletion (ac-ft/mon) | Regulated Flow (ac-ft/month) | Unapprop Flow (ac-ft/mon) |
|---|---|---|---|---|
| A | 180 | 80 | 100 | 0 |
| B | 200 | 60* | 60 | 0 |
| C | 300 | 90 | 70 | 0 |
| D | 350 | 120 | 0 | 0 |

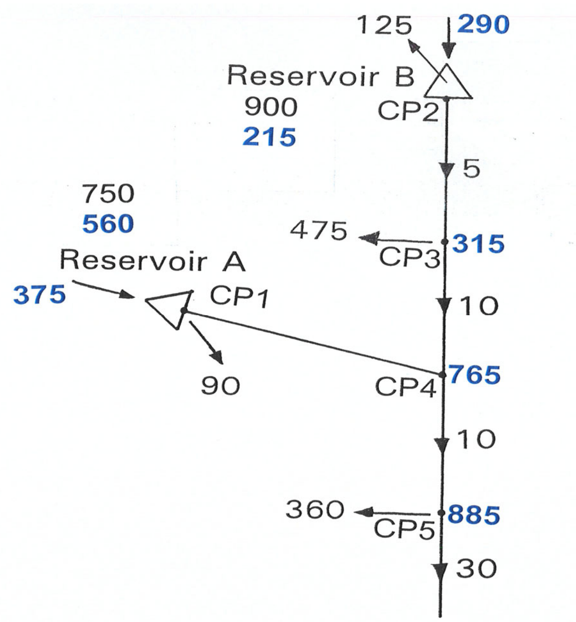
*Diversion shortage of 15 occurs at control point B.

## Second Example of SIM Simulation Procedure

Computations for the river/reservoir system shown in the schematic are performed for one month of a SIM simulation. Water rights input data are provided in the tables and also as IF, WR, and WS records. There are no channel losses. EV record net evaporation less precipitation for this month is zero for both reservoirs.

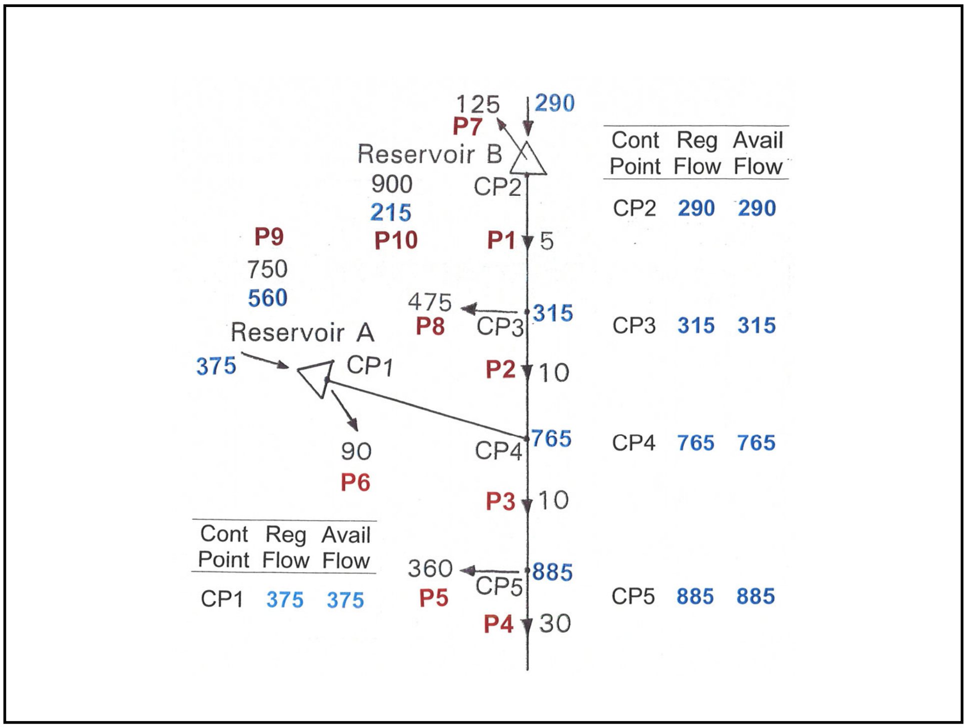
| CP | Naturalized Flow $10^3$ ac-ft | Instream Target $10^3$ ac-ft | Diversion Target $10^3$ ac-ft | Diversion Priority |
|---|---|---|---|---|
| 1 | 375 | -0- | 90 | 19540308 |
| 2 | 290 | 5 | 125 | 19860205 |
| 3 | 315 | 10 | 475 | 19960101 |
| 4 | 765 | 10 | -0- | none |
| 5 | 885 | 30 | 360 | 19421001 |

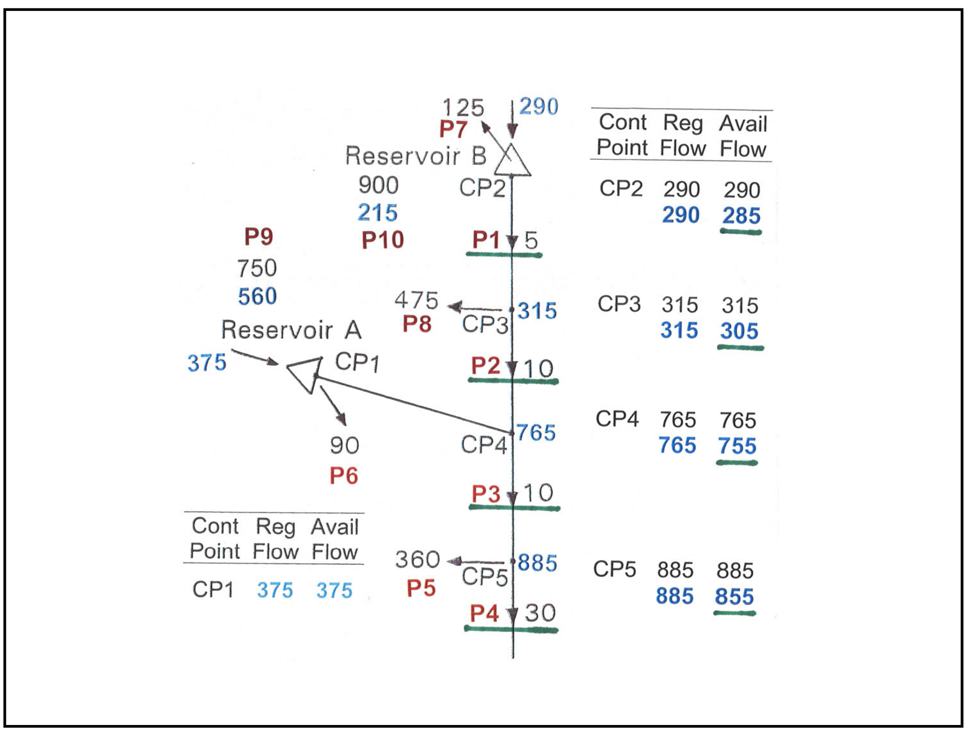
| Storage | Capacity $10^3$ ac-ft | Initial $10^3$ ac-ft |
|---|---|---|
| Reservoir A | 750 | 560 |
| Reservoir B | 900 | 215 |

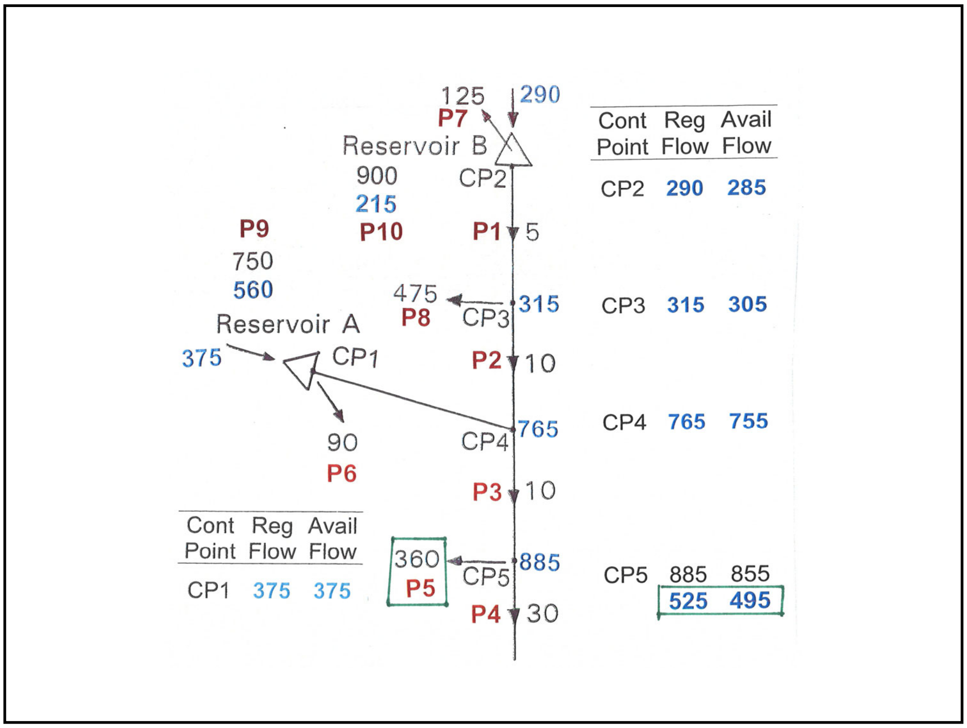


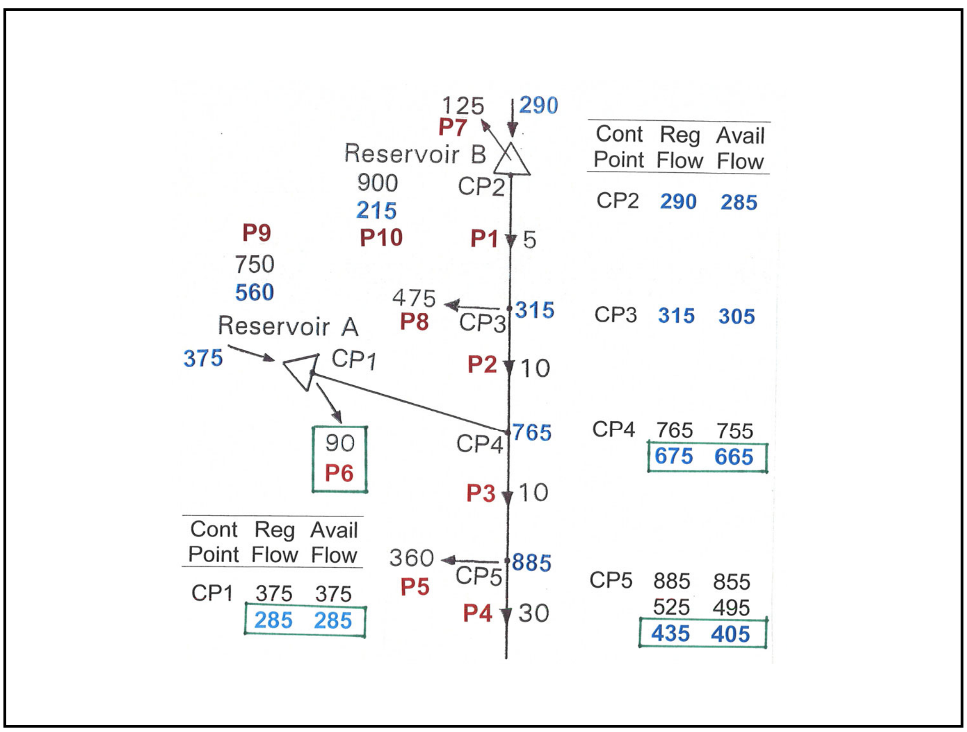

## SIM Water Right Input Records

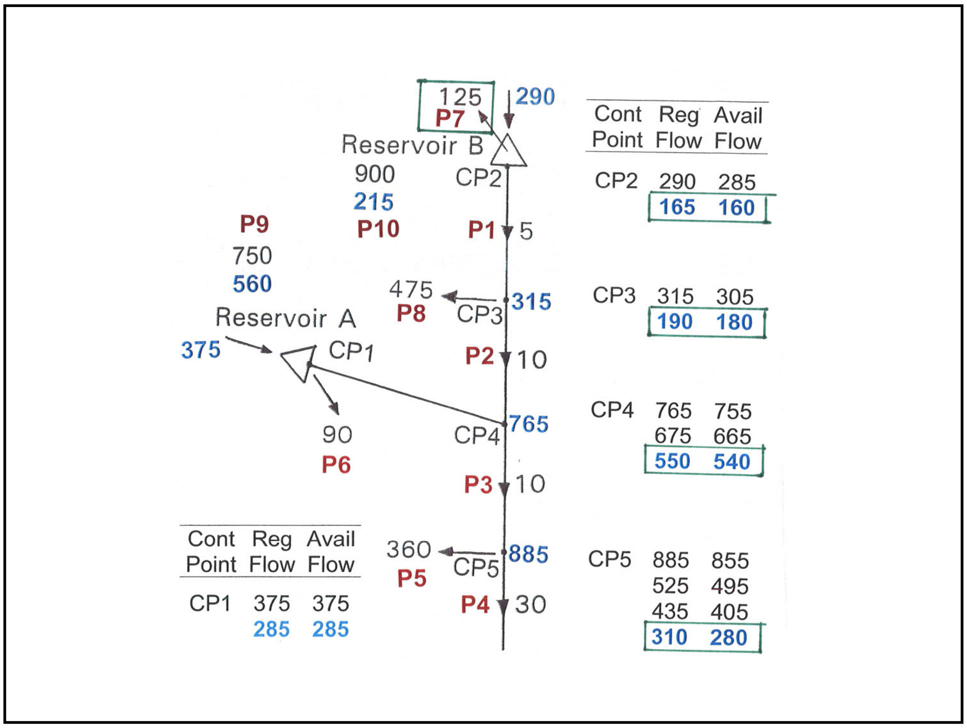
| | | | | | |
|---|---|---|---|---|---|
| IF | CP2 | 60000 | | 1 | |
| IF | CP3 | 12000 | | 2 | |
| IF | CP4 | 12000 | | 3 | |
| IF | CP5 | 36000 | | 4 | |
| WR | CP1 | 1080000 | | 19540308 | 2 |
| WS | RES1 | 750000 | | | |
| WR | CP2 | 1500000 | | 19860205 | 2 |
| WS | RES2 | 900000 | | | |
| WR | CP3 | 5700000 | | 19960101 | 2 |
| WS | RES2 | 900000 | | | |
| WR | CP5 | 4320000 | | 19480820 | 2 |
| WS | RES1 | 750000 | | | |
| WS | RES2 | 900000 | | | |
| WR | CP1 | | | 99999999 | 1 |
| WS | RES1 | 750000 | | | |
| WR | CP2 | | | 99999999 | 1 |
| WS | RES2 | 900000 | | | |

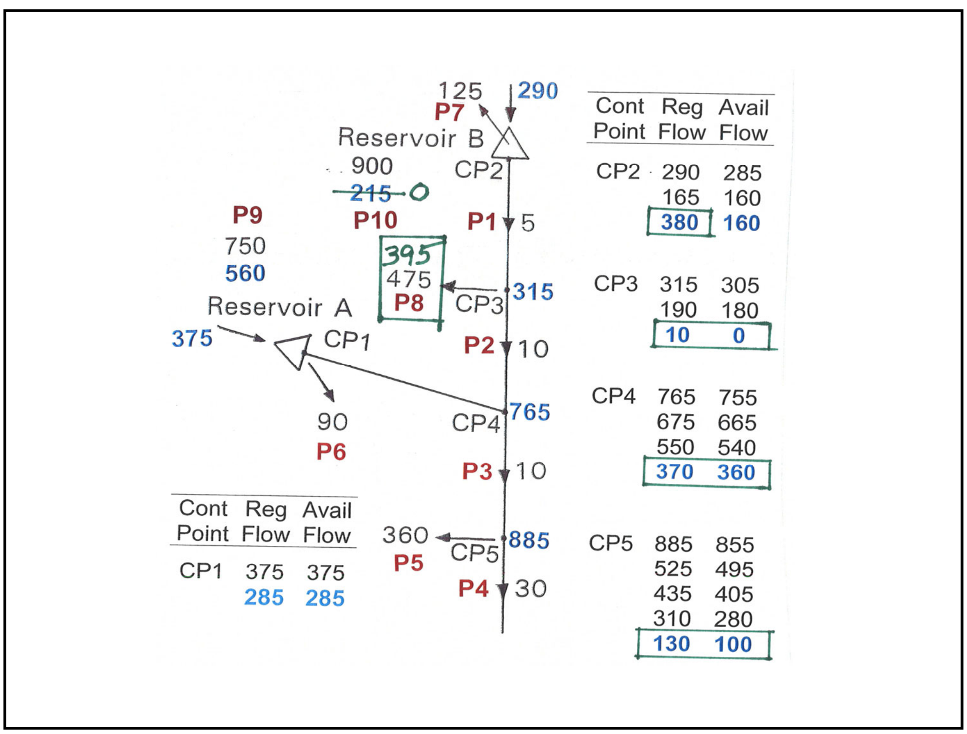

125
290
P7
Reservoir B
900
215
P10
CP2
P9
750
560
P1 5
475
P8
CP3
315
Reservoir A
375
CP1
P2 10
765
CP4
90
P6
P3 10
360
885
CP5
P5
P4 30
Cont Point Reg Flow Avail Flow
CP1 375 375
CP2 290 290
CP3 315 315
CP4 765 765
CP5 885 885

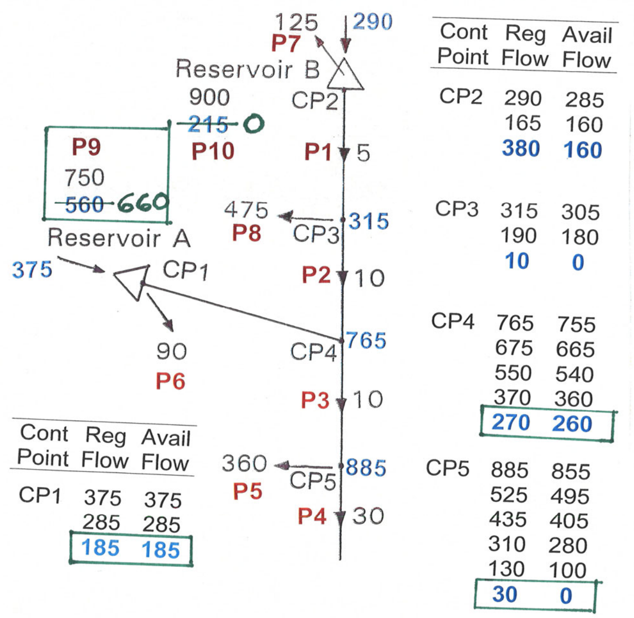

125
290
P7
Reservoir B
900
215
P10
CP2
P9
750
560
P1 5
475
P8
CP3
315
Reservoir A
375
CP1
P2 10
765
CP4
90
P6
P3 10
360
885
CP5
P5
P4 30
Cont Point Reg Flow Avail Flow
CP1 375 375
CP2 290 290
290 285
CP3 315 315
315 305
CP4 765 765
765 755
CP5 885 885
885 855


125
290
P7
Reservoir B
900
215
P10
CP2
P9
750
560
P1 5
475
P8
CP3
315
Reservoir A
375
CP1
P2 10
765
CP4
90
P6
P3 10
360
P5
CP5
885
P4 30
Cont Point | Reg Flow | Avail Flow
CP1 375 375
CP2 290 285
CP3 315 305
CP4 765 755
CP5 885 855
525 495


125
290
P7
Reservoir B
900
215
P10
CP2
P9
750
560
P1 5
475
P8
CP3
315
Reservoir A
375
CP1
P2 10
765
CP4
90
P6
P3 10
360
P5
CP5
885
P4 30
Cont Point | Reg Flow | Avail Flow
CP1 375 375
285 285
CP2 290 285
CP3 315 305
CP4 765 755
675 665
CP5 885 855
525 495
435 405


125
P7
290
Reservoir B
900
215
P10
CP2
P9
750
560
P1
5
475
P8
CP3
315
Reservoir A
375
CP1
P2
10
765
CP4
90
P6
P3
10
360
P5
CP5
885
P4
30
Cont Point | Reg Flow | Avail Flow
CP1 375 375
285 285
Cont Point | Reg Flow | Avail Flow
CP2 290 285
165 160
CP3 315 305
190 180
CP4 765 755
675 665
550 540
CP5 885 855
525 495
435 405
310 280


125
P7
290
Reservoir B
900
215 0
P10
CP2
P9
750
560
P1
5
395
475
P8
CP3
315
Reservoir A
375
CP1
P2
10
765
CP4
90
P6
P3
10
360
P5
CP5
885
P4
30
Cont Point | Reg Flow | Avail Flow
CP1 375 375
285 285
Cont Point | Reg Flow | Avail Flow
CP2 290 285
165 160
380 160
CP3 315 305
190 180
10 0
CP4 765 755
675 665
550 540
370 360
CP5 885 855
525 495
435 405
310 280
130 100




## Simulation Results for the Month

| Control Point | Natural Flow | Regulated Flow | Unappro Flow | Diversion | Reservoir Storage |
|---|---|---|---|---|---|
| CP1 | 375 | 185 | 0 | 90 | 660 |
| CP2 | 290 | 380 | 0 | 125 | 0 |
| CP3 | 315 | 10 | 0 | 395* | - |
| CP4 | 765 | 270 | 0 | - | - |
| CP5 | 885 | 30 | 0 | 360 | - |

*Diversion shortage of 80 at CP3.

## Basics of Water Availability Modeling with the Water Rights Analysis Package (WRAP)

## Module 7 - Supply Reliability, Flow and Storage Frequency, and other Analyses of Simulation Results

Presented by Ralph Wurbs, Ph.D., P.E.
Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the

Texas Commission on Environmental Quality

## Seven Modules of Course on Basics of Water Availability Modeling with WRAP

1. Overview of WRAP/WAM Modeling System
2. WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records
3. Executing Programs and Managing Files and Records
4. Hydrology Features of the Modeling System
5. Simulation of Water Management
6. Simulation Model Computational Algorithms
7. **Supply Reliability, Flow and Storage Frequency, and Other Analyses of Simulation Results (this module)**

## Water Availability Assessment

***Historical Natural Hydrology***

The SIM simulation is performed with input hydrologic period-of-analysis sequences of monthly naturalized flows and reservoir net evaporation-precipitation rate.

***Specified Water Development, Management, and Use Scenario***

SIM simulates a specified scenario of water resources development, allocation, regulation, management, and use.

***Organization, Display, and Analyses of Simulation Results***

Simulation results are organized as metrics of supply reliability and flow and storage frequency and other measures of water availability.

## SIM DAT File Input Records that Control SIM Simulation Results in OUT and DSS Files

JD record OUTCP and OUTWR options for control points and water rights (all, none, or specified categories) to include in OUT and/or DSS output files (Fundamentals Manual page 76).

CO, RO, WO, GO records listing control points, reservoirs, water rights, and water right groups to include in OUT and/or DSS output files (Fundamentals Manual page 81).

OF Record DSS file options that include selecting simulation results variables to record in DSS output file (FM pages 79-80).

## Counts of Control Points, Water Rights, and Reservoirs

Fundamentals Manual Example
11 control points
30 water rights
6 reservoirs

Brazos WAM
3,842 control points
1,643 water rights
678 reservoirs

## Example 1940-2017 Time Series

78 years
936 months
28,490 days

### 16 Control Point Output Variables
### Selected with OF Record

1. naturalized stream flow (NAT)
2. regulated stream flow (REG)
3. unappropriated stream flow (UNA)
4. channel loss credits (CLC)
5. channel losses (CLO)
6. return flows returned here (RFR)
7. upstream reservoir releases (URR)
8. control point inflows (CPI)
9. end-of-month reservoir storage (STO)
10. reservoir net evaporation volume (EVA)
11. stream flow depletions (DEP)
12. diversion target (TAR)
13. diversion shortage (SHT)
14. diversion amount (DIV)
15. instream flow target (IFT)
16. instream flow shortage (IFS)

### 15 Water Right Output Variables
### Selected with OF Record

17. reservoir storage volume (STO)
18. reservoir net evaporation volume (EVA)
19. stream flow depletion (DEP)
20. diversion or hydropower target (TAR)
21. diversion or energy shortage (SHT)
22. diversion or energy amount (DIV)
23. available stream flow (ASF)
24. releases from secondary reservoirs (ROR)
25. return flow (RFL)
26. available increase (XAV)
27. instream flow IF record target (TIF)
28. Instream flow IF right target (IFT)
29. Instream flow IF right shortage (IFS)
30. Instream flow IF right *FS* record flow (FSV)
31. Instream flow IF right *FS* record count (FSC)

## 12 Reservoir and Hydropower Output Variables Selected with OF Record

32. end-of-month reservoir storage (STO)
33. net evaporation-precipitation volume (EVA)
34. power shortage or secondary energy (HPS)
35. hydroelectric energy generated (HPE)
36. inflows from stream flow depletions (RID)
37. inflows from reservoir releases (RIR)
38. releases accessible to hydropower (RAH)
39. releases not accessible to hydro (RNA)
40. adjusted evaporation-precipitation depth (EPD)
41. net evaporation depths (EVR)
42. reservoir water surface elevation (WSE)
43. reservoir storage capacity (RSC)

## Simulation Results Time Series Variables and Other Time Series Variables Derived Therefrom Read By and Output from TABLES and HEC-DSSVue

43 monthly time series in SIM output OUT and DSS files.

43 daily time series in SIMD output OUT and DSS files.

43 monthly summations of daily quantities in SIMD OUT/DSS files.

Annual time series derived from monthly or daily time series such as annual totals, minimum or maximum monthly or daily quantities in each year (or x-month or x-day such as annual 7-day low flows).

Monthly salinity concentrations and loads from WRAP program SALT.

Note: TABLES and HEC-DSSVue can read and analyze any time series variable including observed flows, precipitation, evaporation, and other data not related to simulation results.

## WRAP Program TABLES

Fundamentals Manual, *Chapter 4 Organization and Analysis of Simulation Results with TABLES and HEC-DSSVue*.

Fundamentals Manual, *Appendix B TABLES Files for the Example*.

Fundamentals Manual, *Appendix D TABLES Input Records.*

Users Manual, *Chapter 5 Program TABLES.*

Reference Manual, *Chapter 7 Program TABLES Analyses of Simulation Input and Results.*

## Types of Tables Produced by TABLES

(Users Manual Table 5.2 Input Records and Associated Tables)

Type 1 – Tables created from SIM input DAT file data

Type 2 – Tables created from SIM output OUT or DSS file data

- Reliability tables and frequency analysis tables
- Summary tables and water budget tables
- Time series tabulations in alternative formats
- Conversions between text file and DSS file formats

Type 3 – Creation of SIM input records from SIM output OUT file data

Type 4 – Tables created from SIM output HRR and ZZZ files

Type 5 – Conditional reliability tables from SIM output CRM file data

Type 6 – Tables similar to Type 2 created from daily SIMD SUB file data

Type 7 – Probability analyses of annual series from DSS or SIMD AFF file

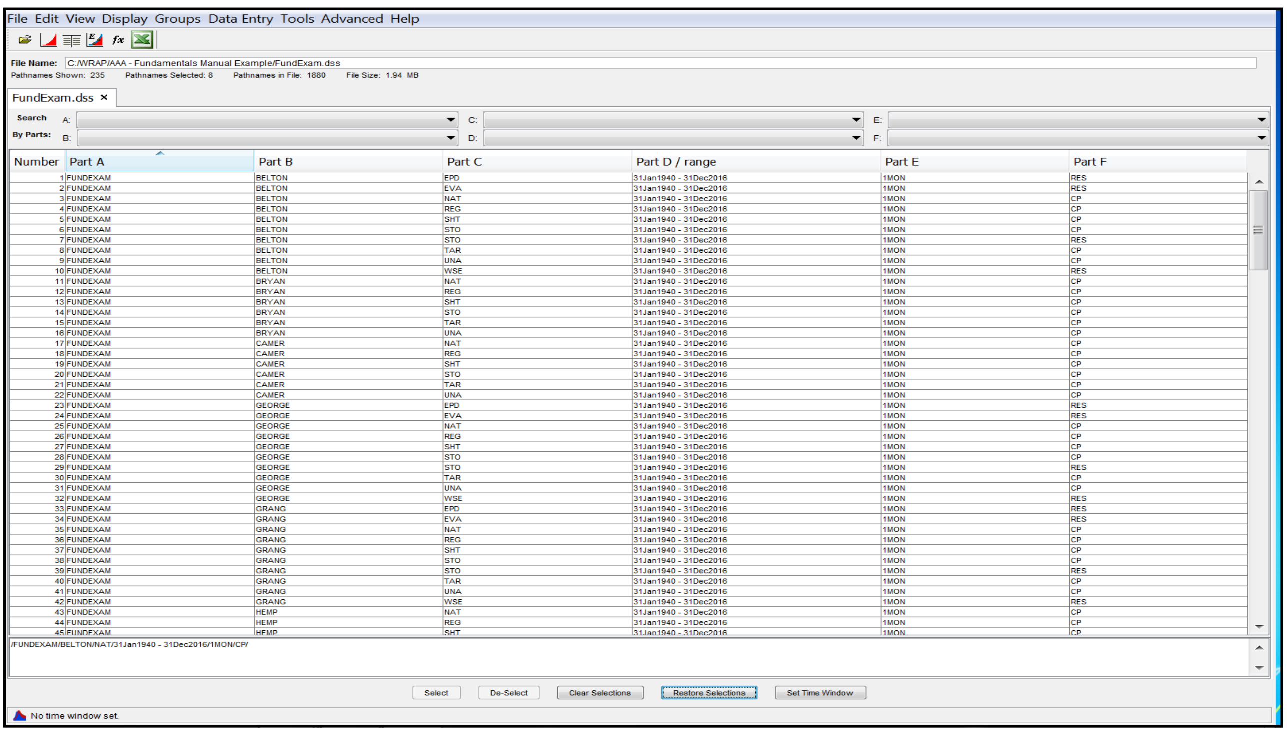
Type 8 – Salinity simulation results from SALT output SAL file data

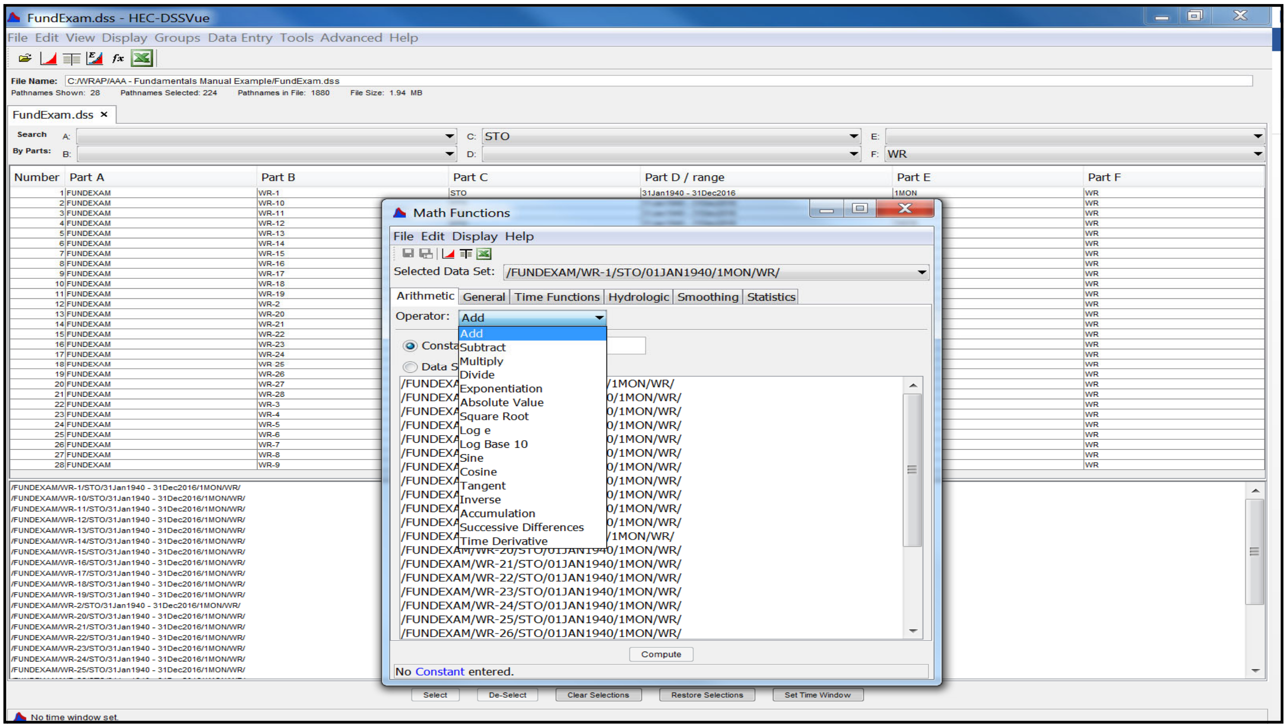
## HEC-DSSVue

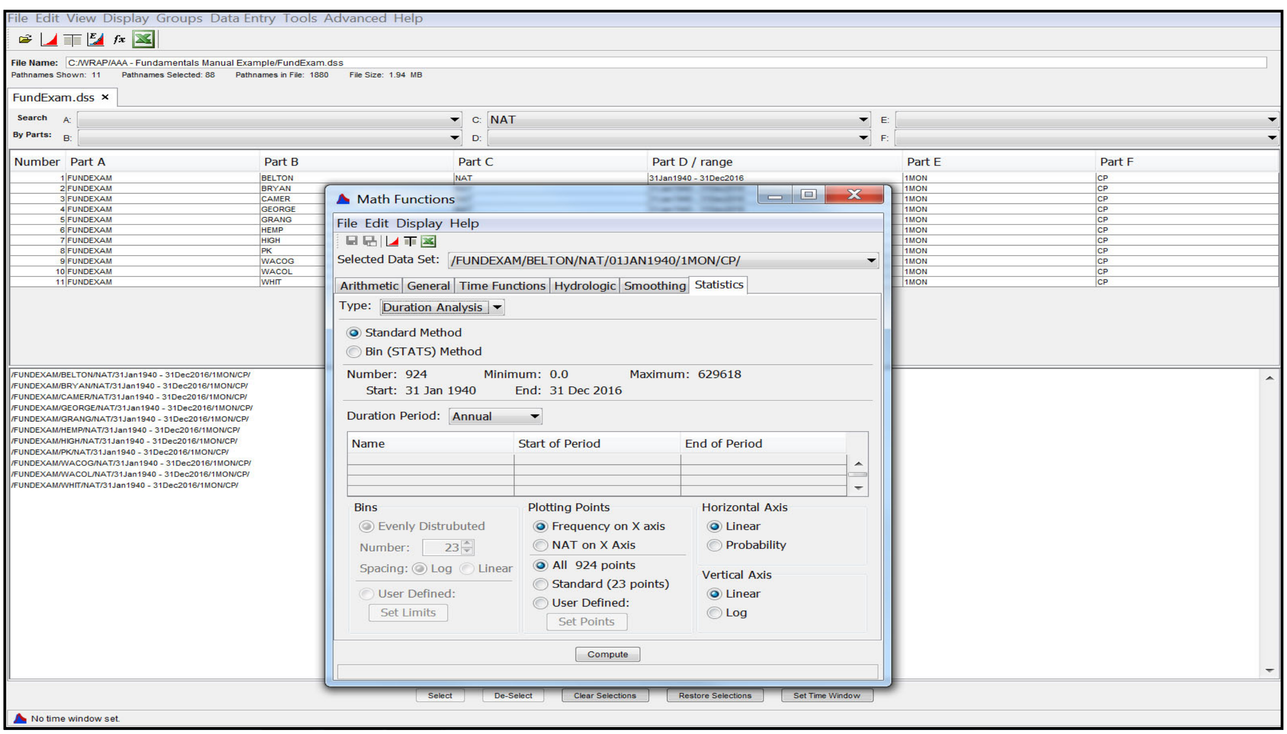
WRAP Users Manual, *Chapter 6 HEC-DSS Data Storage System and HEC-DSSVue* (22 pages).

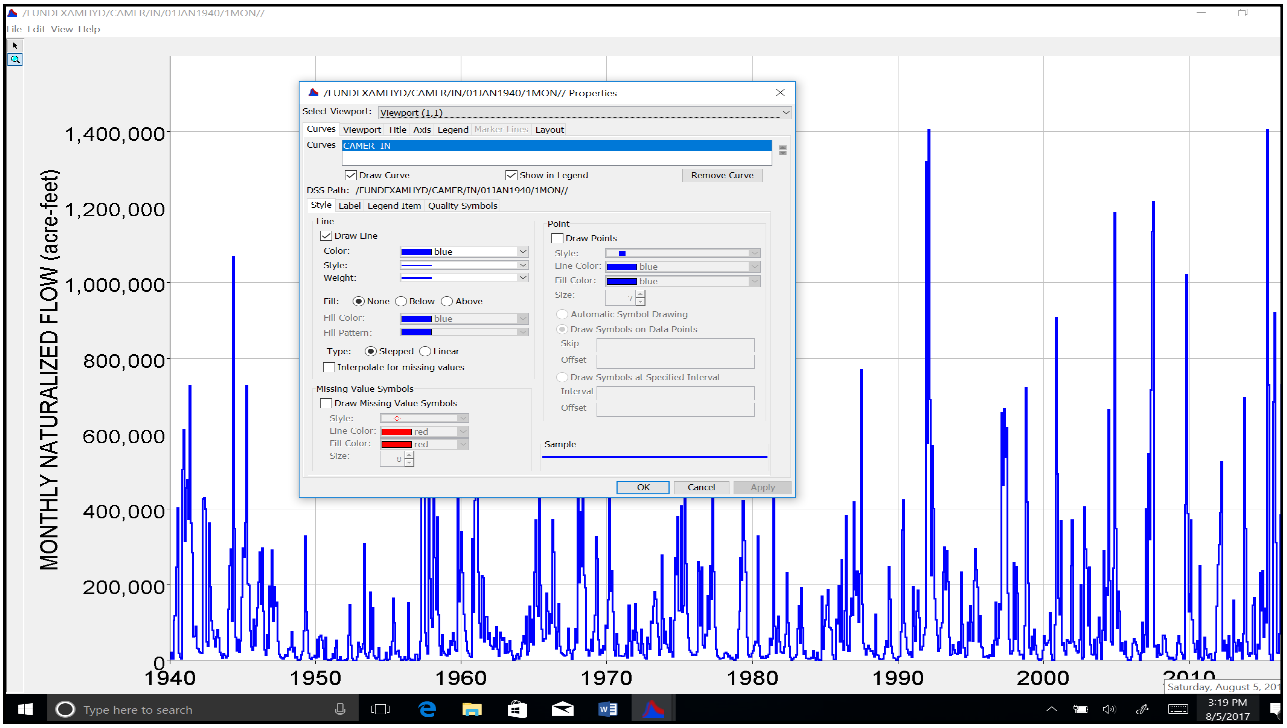
HEC-DSSVue User's Manual (465 pages) is available for download as a PDF along with the HEC-DSSVue software from the USACE HEC website.

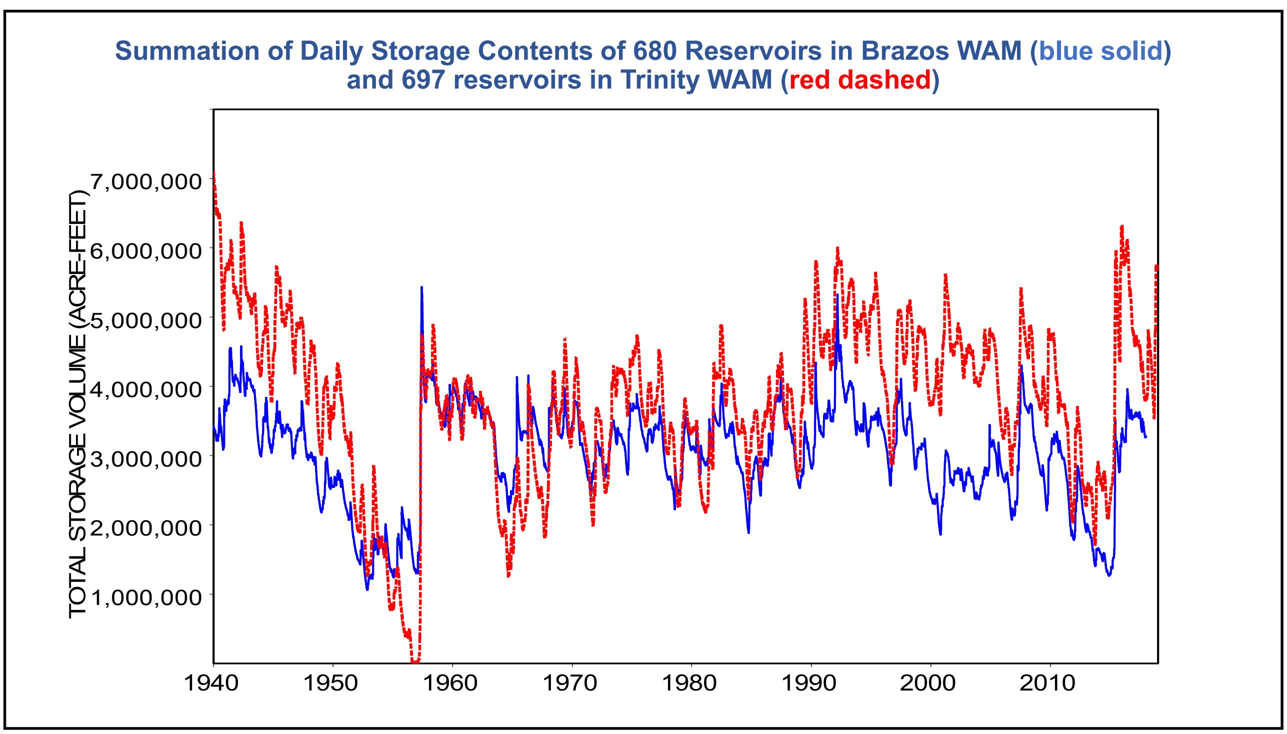
https://www.hec.usace.army.mil/software/hec-dssvue/



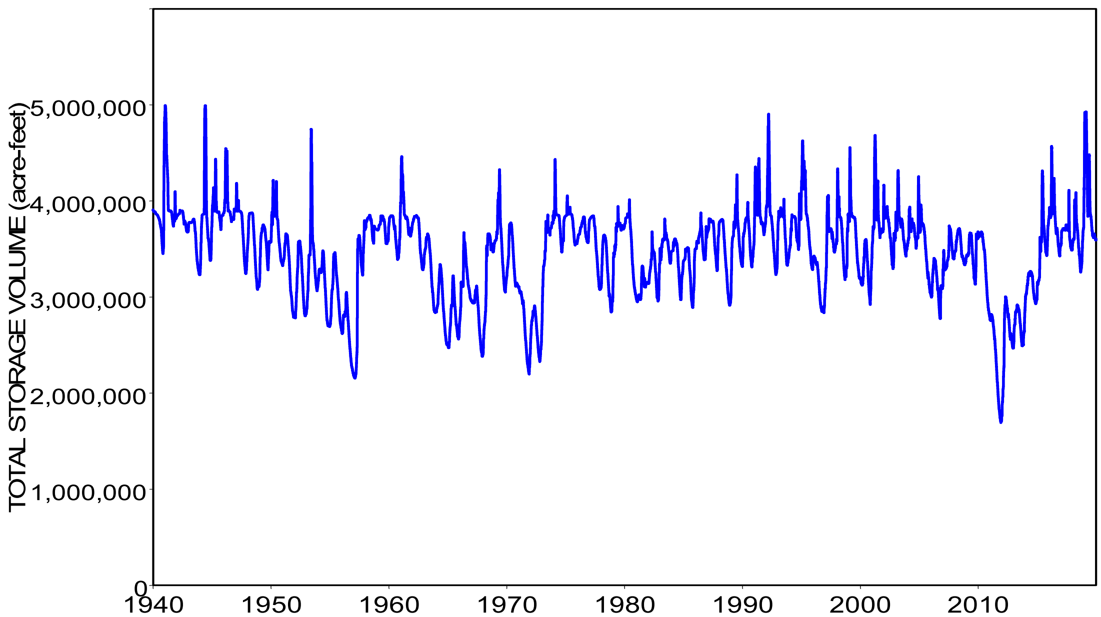

FundExam.dss - HEC-DSSVue
File Edit View Display Groups Data Entry Tools Advanced Help
File Name: C:/WRAP/AAA - Fundamentals Manual Example/FundExam.dss
Pathnames Shown: 28 Pathnames Selected: 224 Pathnames in File: 1880 File Size: 1.94 MB
FundExam.dss
Search By Parts:
C: STO
F: WR
Number Part A Part B Part C Part D / range Part E Part F
Math Functions
File Edit Display Help
Selected Data Set: /FUNDEXAM/WR-1/STO/01JAN1940/1MON/WR/
Arithmetic General Time Functions Hydrologic Smoothing Statistics
Operator: Add
Add
Subtract
Multiply
Divide
Exponentiation
Absolute Value
Square Root
Log e
Log Base 10
Sine
Cosine
Tangent
Inverse
Accumulation
Successive Differences
Time Derivative
Compute
No Constant entered.
Select De-Select Clear Selections Restore Selections Set Time Window
No time window set.


File Edit View Display Groups Data Entry Tools Advanced Help
File Name: C:/WRAP/AAA - Fundamentals Manual Example/FundExam.dss
Pathnames Shown: 11 Pathnames Selected: 88 Pathnames in File: 1880 File Size: 1.94 MB
FundExam.dss
C: NAT
Number Part A Part B Part C Part D / range Part E Part F
Math Functions
File Edit Display Help
Selected Data Set: /FUNDEXAM/BELTON/NAT/01JAN1940/1MON/CP/
Arithmetic General Time Functions Hydrologic Smoothing Statistics
Type: Duration Analysis
Standard Method
Bin (STATS) Method
Number: 924 Minimum: 0.0 Maximum: 629618
Start: 31 Jan 1940 End: 31 Dec 2016
Duration Period: Annual
Name Start of Period End of Period
Bins
Evenly Distributed
Number: 23
Spacing: Log Linear
User Defined:
Set Limits
Plotting Points
Frequency on X axis
NAT on X Axis
All 924 points
Standard (23 points)
User Defined:
Set Points
Horizontal Axis
Linear
Probability
Vertical Axis
Linear
Log
Compute
Select De-Select Clear Selections Restore Selections Set Time Window
No time window set.


/FUNDEXAMHYD/CAMER/IN/01JAN1940/1MON//
File Edit View Help
MONTHLY NATURALIZED FLOW (acre-feet)
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1940
1950
1960
1970
1980
1990
2000
2010
/FUNDEXAMHYD/CAMER/IN/01JAN1940/1MON// Properties
Select Viewport: Viewport (1,1)
Curves Viewport Title Axis Legend Marker Lines Layout
Curves CAMER IN
Draw Curve
Show in Legend
Remove Curve
DSS Path: /FUNDEXAMHYD/CAMER/IN/01JAN1940/1MON//
Style Label Legend Item Quality Symbols
Line
Draw Line
Color: blue
Style:
Weight:
Fill: None Below Above
Fill Color: blue
Fill Pattern:
Type: Stepped Linear
Interpolate for missing values
Missing Value Symbols
Draw Missing Value Symbols
Style:
Line Color: red
Fill Color: red
Size:
Point
Draw Points
Style:
Line Color: blue
Fill Color: blue
Size:
Automatic Symbol Drawing
Draw Symbols on Data Points
Skip
Offset
Draw Symbols at Specified Interval
Interval
Offset
Sample
OK
Cancel
Apply
Type here to search
3:19 PM
8/5/2017


Summation of Daily Storage Contents of 680 Reservoirs in Brazos WAM (blue solid)
and 697 reservoirs in Trinity WAM (red dashed)
TOTAL STORAGE VOLUME (ACRE-FEET)
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
1940
1950
1960
1970
1980
1990
2000
2010

**Summation of 1940-2019 Daily Storage Contents of 180 Reservoirs in Neches WAM**




## TABLES Reliability 2REL Record Parameters

(Fundamentals Manual pages 103-104, Users Manual pages 209-212)

MON – All months or selected month (January - December) for analysis.
RFLAG – Default is for N to be number of months with non-zero targets.
Optionally, N can be the total number of months in simulation.
ID – Reliabilities for control point summations, summations for groups of water rights, water supply diversion rights, hydroelectric power.
NUM – All or selected control points, water rights, or hydropower reservoirs.
FAMT – Minimum limit on annual target for inclusion in the table.
XAMT (target), XPS & XPJ (priority), XCP (location), XUSE (use type), XGROUP (group identifiers) parameters for defining water rights to include.
TAR – Optional additional supplemental reliability table is created.
VUL – Optional table with vulnerability and resiliency metrics is created.

## TABLES Frequency 2FRE Record Parameters

(Fundamentals Manual pages 105-106, User Manual pages 213-215)

Variable ID – Variable for which frequency analysis is performed.
MON – All months or selected month (January - December) for analysis.
NUM – All or selected control points, water rights, or reservoirs.
TABLE – Alternative optional formats for frequency table.
METHOD – (1) relative frequency formula, (2) log-normal distribution, (3) normal probability distribution, or (4) Weibull formula.
CFS – Option to convert from acre-feet to cfs.
MAT – Option to convert to moving averages or moving totals
TIME – Number of months for moving averages or totals.
XF – Multiplier factor with default of 1.0
AF – Addition factor with default of 0.0
XLIMIT – Minimum limit of mean for inclusion in table.

## Program TABLES
## Reliability and Frequency Tables

### Volume Reliability

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

### Period Reliability

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

### Exceedance Frequency

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

## TABLES 2FRE Record Frequency Table (Format Option 1)
(Fundamentals Manual, page 66)

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

| CONTROL POINT | MEAN | STANDARD DEVIATION | 100% | 99% | 98% | 95% | 90% | 75% | 60% | 50% | 40% | 25% | 10% | MAXIMUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PK | 57843.2 | 123894. | 0.0 | 0.0 | 0.0 | 0.0 | 1384.4 | 5866.0 | 10695. | 15700. | 24830. | 54063. | 143746. | 1794495. |
| Whit | 107505.2 | 194568. | 0.0 | 0.0 | 1138.3 | 3263.4 | 6206.6 | 15341.0 | 25966. | 39379. | 60919. | 115994. | 269125. | 2981239. |
| WacoL | 29848.8 | 53414. | 0.0 | 0.0 | 0.0 | 0.0 | 245.4 | 2301.0 | 5536. | 9088. | 14595. | 34506. | 81659. | 526506. |
| WacoG | 155102.4 | 258754. | 0.0 | 526.8 | 1833.4 | 5110.8 | 9745.8 | 22309.0 | 40522. | 63432. | 97423. | 175996. | 408190. | 3376485. |
| High | 188086.6 | 294671. | 0.0 | 1988.0 | 3555.4 | 8162.6 | 13905.4 | 28093.0 | 53733. | 78796. | 120185. | 219665. | 471562. | 3599267. |
| Belton | 41676.1 | 74102. | 0.0 | 0.0 | 0.0 | 183.8 | 923.0 | 3929.0 | 8236. | 13046. | 21749. | 44896. | 111761. | 629875. |
| George | 4715.3 | 8748. | 0.0 | 0.0 | 0.0 | 0.0 | 58.6 | 260.0 | 692. | 1187. | 1983. | 5179. | 13983. | 76105. |
| Grang | 16074.9 | 25765. | 0.0 | 0.0 | 0.0 | 62.8 | 456.8 | 1752.0 | 3711. | 5454. | 8659. | 20102. | 45868. | 212283. |
| Camer | 111137.1 | 173050. | 0.0 | 208.6 | 930.6 | 2610.2 | 5008.0 | 14985.0 | 29186. | 44782. | 65285. | 131624. | 296162. | 1403134. |
| Bryan | 330468.1 | 485044. | 0.0 | 5076.2 | 8044.3 | 15700.2 | 26182.8 | 55094.0 | 102384. | 150473. | 227305. | 401884. | 787075. | 4704304. |
| Hemp | 445434.5 | 595319. | 107.0 | 10926.5 | 14500.9 | 26049.8 | 41961.6 | 81990.0 | 149836. | 222890. | 311503. | 572999. | 1152708. | 5723474. |

## TABLES 2FRE Record Frequency Table (Format Option 2)
(Fundamentals Manual, page 67)

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

| CP | PK | Whit | WacoL | WacoG | High | Belton | George | Grang | Camer | Bryan | Hemp |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 34636.34 | 63973.88 | 21773.80 | 121648.99 | 151589.95 | 25993.00 | 2780.60 | 11382.29 | 82452.66 | 264061.00 | 328642.34 |
| Std Dev | 108900.59 | 175850.83 | 51597.56 | 232488.81 | 266901.44 | 65967.44 | 7462.23 | 23129.21 | 156926.16 | 439612.41 | 552265.00 |
| Minimum | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9205.48 |
| 99.5% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 276.16 | 4278.47 | 9205.48 |
| 99% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 295.89 | 10210.74 | 9863.00 |
| 98% | 0.00 | 0.00 | 0.00 | 983.84 | 857.36 | 0.00 | 0.00 | 0.00 | 295.89 | 17160.69 | 9863.01 |
| 95% | 0.00 | 0.00 | 0.00 | 5922.81 | 7066.87 | 0.00 | 0.00 | 0.00 | 295.89 | 27039.04 | 9863.01 |
| 90% | 0.00 | 0.00 | 0.00 | 12276.08 | 16958.64 | 0.00 | 0.00 | 0.00 | 305.75 | 36655.40 | 10191.78 |
| 85% | 0.00 | 0.00 | 0.00 | 19062.36 | 25394.47 | 0.00 | 0.00 | 0.00 | 305.75 | 42141.98 | 10191.78 |
| 80% | 0.00 | 0.00 | 0.00 | 25226.75 | 31153.97 | 0.00 | 0.00 | 0.00 | 1949.61 | 48809.81 | 10191.78 |
| 75% | 0.00 | 0.00 | 0.00 | 29773.20 | 35121.22 | 0.00 | 0.00 | 0.00 | 3902.65 | 54517.21 | 10191.78 |
| 70% | 0.00 | 0.00 | 0.00 | 32821.61 | 39671.35 | 0.00 | 0.00 | 0.00 | 6366.40 | 58945.04 | 17232.20 |
| 60% | 0.00 | 0.00 | 0.00 | 39114.92 | 49071.03 | 0.00 | 0.00 | 0.00 | 11116.47 | 70806.62 | 47505.39 |
| 50% | 0.00 | 0.00 | 0.00 | 47768.53 | 59178.02 | 0.00 | 0.00 | 0.00 | 20151.04 | 87841.74 | 92210.49 |
| 40% | 0.00 | 18374.49 | 0.00 | 64706.23 | 77944.01 | 2664.95 | 0.00 | 2481.44 | 39477.36 | 121603.63 | 170176.91 |
| 30% | 18981.27 | 41465.81 | 8453.52 | 79765.54 | 109017.78 | 10059.44 | 0.00 | 9450.27 | 63027.98 | 207966.80 | 304222.28 |
| 25% | 29340.66 | 53437.19 | 16009.90 | 95011.06 | 134277.52 | 15457.19 | 260.00 | 11255.58 | 86065.99 | 285932.06 | 413997.06 |
| 20% | 45053.14 | 64011.85 | 30953.28 | 127052.32 | 189532.19 | 33716.60 | 2897.15 | 17629.11 | 117443.84 | 377628.78 | 541721.06 |
| 15% | 56908.62 | 95319.14 | 44268.99 | 187459.61 | 254532.44 | 52882.22 | 5755.95 | 25126.00 | 164552.14 | 498738.94 | 716312.00 |
| 10% | 78962.93 | 177289.41 | 70962.08 | 297903.69 | 381052.28 | 73961.51 | 9600.50 | 38537.19 | 224108.41 | 668371.38 | 973661.69 |
| 5% | 166127.38 | 336957.66 | 126230.95 | 554376.06 | 686392.62 | 141653.08 | 18278.58 | 60167.34 | 385609.44 | 1108598.62 | 1397635.50 |
| 2% | 408854.03 | 670201.19 | 212007.28 | 814163.31 | 981440.81 | 241334.81 | 28034.03 | 85773.74 | 591658.06 | 1756610.12 | 2117796.75 |
| 1% | 513265.78 | 845458.31 | 269009.84 | 1142404.88 | 1294697.88 | 382446.81 | 35370.34 | 110916.23 | 744026.88 | 2191469.25 | 2471481.50 |
| 0.5% | 696401.94 | 1092618.38 | 300005.69 | 1428372.62 | 1650678.25 | 495287.16 | 52599.12 | 144253.72 | 1073530.88 | 2658072.25 | 3127660.75 |
| Maximum | 1783135.12 | 2971574.25 | 524844.50 | 3363118.50 | 3582674.00 | 552012.56 | 73807.57 | 200139.30 | 1392594.88 | 4523927.50 | 5492297.00 |

## TABLES 2REL Record Reliability Table

(Fundamentals Manual, page 68)

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

| NAME | TARGET DIVERSION (AC-FT/YR) | MEAN SHORTAGE (AC-FT/YR) | *RELIABILITY* PERIOD (%) | *RELIABILITY* VOLUME (%) | PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100% | 95% | 90% | 75% | 50% | 25% | 1% | PERCENTAGE OF YEARS 100% | 98% | 95% | 90% | 75% | 50% | 1% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PK | 254800.0 | 8910.30 | 94.87 | 96.50 | 94.9 | 94.9 | 95.0 | 95.1 | 95.8 | 97.0 | 99.5 | 85.9 | 85.9 | 88.5 | 92.3 | 96.2 | 97.4 | 100.0 |
| Whit | 18000.0 | 1515.04 | 91.88 | 91.58 | 91.9 | 91.9 | 91.9 | 91.9 | 92.0 | 92.3 | 92.4 | 74.4 | 74.4 | 74.4 | 76.9 | 85.9 | 94.9 | 100.0 |
| WacoL | 80800.0 | 0.00 | 100.00 | 100.00 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| WacoG | 32300.0 | 1957.95 | 96.69 | 93.94 | 96.7 | 96.8 | 96.9 | 97.0 | 97.5 | 98.2 | 98.6 | 75.6 | 78.2 | 78.2 | 79.5 | 88.5 | 98.7 | 100.0 |
| High | 44800.0 | 4095.52 | 95.51 | 90.86 | 95.5 | 95.7 | 95.8 | 96.2 | 96.9 | 97.2 | 97.6 | 62.8 | 66.7 | 67.9 | 73.1 | 82.1 | 93.6 | 100.0 |
| Belton | 180260.0 | 7589.74 | 94.34 | 95.79 | 94.3 | 94.4 | 94.4 | 94.7 | 95.2 | 96.6 | 98.7 | 84.6 | 84.6 | 87.2 | 88.5 | 93.6 | 96.2 | 100.0 |
| George | 25610.0 | 3438.62 | 83.44 | 86.57 | 83.4 | 83.8 | 84.0 | 84.9 | 86.2 | 88.1 | 95.0 | 67.9 | 67.9 | 69.2 | 73.1 | 80.8 | 87.2 | 100.0 |
| Grang | 42000.0 | 2598.82 | 91.24 | 93.81 | 91.2 | 91.5 | 91.7 | 92.3 | 93.5 | 95.9 | 97.9 | 79.5 | 80.8 | 82.1 | 85.9 | 89.7 | 94.9 | 100.0 |
| Camer | 209600.0 | 33523.84 | 80.24 | 84.01 | 80.2 | 81.5 | 82.5 | 84.7 | 91.8 | 97.9 | 99.6 | 15.4 | 17.9 | 25.6 | 41.0 | 76.9 | 94.9 | 100.0 |
| Bryan | 98900.0 | 4489.08 | 90.71 | 95.46 | 90.7 | 90.9 | 91.2 | 95.3 | 99.3 | 99.8 | 99.9 | 48.7 | 52.6 | 67.9 | 80.8 | 96.2 | 100.0 | 100.0 |
| Hemp | 694700.0 | 35096.32 | 85.58 | 94.95 | 85.6 | 87.9 | 90.2 | 94.8 | 98.6 | 99.1 | 99.9 | 33.3 | 44.9 | 64.1 | 85.9 | 97.4 | 100.0 | 100.0 |
| Total | 1681770.0 | 103215.23 | | 93.86 | | | | | | | | | | | | | | |

## SIM Automated Iterative Firm Yield Algorithm

Firm yield is the maximum annual diversion target that can be maintained throughout the simulation with no shortages. Thus, the firm yield is the estimated maximum diversion with volume and period reliabilities of 100% based on the SIM simulation with all of its premises and approximations.

Alternative strategies for computing firm yield:

- Multiple trial-and-error SIM simulations with the diversion target manually changed for each execution of SIM.
- Automatic repetition of the simulation computations within a single execution of SIM as specified by the FY record.

## SIM Firm Yield FY Record Parameters

(Fundamentals Manual page 78, Users Manual Pages 55-57)

FYIN(1) – Fraction of monthly target that must be met.
FYIN(2) – Initial value for the annual diversion target.
FYIN(3) – Incremental decrease for first level of decreases.
FYIN(4) – Incremental decrease for second level of decreases.
FYIN(5) – Incremental decrease for third level of decreases.
FYWRID – Water right identifier.
FYGROUP – Water right group identifier.
MFY – Proportional to amounts in WR record field 3.
FYC(1) – The FYIN(1) applies to only period reliability or also firm yield.
FYC(2) – Reservoir storage reserve options.
FYC(3) – Number of months of water supply storage reserve.
FYIN(6) – Required storage reservoir plus inactive storage.

## The SIM simulation produces the following YRO file as specified by the FY record (Table 3.5 on page 38 of Fundamentals Manual).

```
Yield Versus Reliability Table for the Following Water Supply Diversion Right(s):

              One right (100%): WR-24            SystemH

If more than one right, the target amount is distributed using the percentages
shown above. The total number of periods is 936. The period reliability is the
percentage of the periods for which at least 100.0 percent (FY record field 2;
default=100%) of the target is supplied.

The table ends with the maximum target that results in a mean annual shortage
of less than 0.05 units if such a firm yield is possible.
```

## Continuation of SIM YRO File

| Iteration | Level | Annual Target | Mean Shortage | Mean Actual | Volume Reliability (%) | Periods Without Shortage | Period Reliability (%) |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 200000.0 | 922.0 | 199078.0 | 99.54 | 932 | 99.57 |
| 2 | 1 | 190000.0 | 805.8 | 189194.2 | 99.58 | 932 | 99.57 |
| 3 | 1 | 180000.0 | 709.8 | 179290.2 | 99.61 | 932 | 99.57 |
| 4 | 1 | 170000.0 | 551.8 | 169448.2 | 99.68 | 933 | 99.68 |
| 5 | 1 | 160000.0 | 513.9 | 159486.1 | 99.68 | 933 | 99.68 |
| 6 | 1 | 150000.0 | 476.1 | 149523.9 | 99.68 | 933 | 99.68 |
| 7 | 1 | 140000.0 | 437.7 | 139562.2 | 99.69 | 933 | 99.68 |
| 8 | 1 | 130000.0 | 399.9 | 129600.1 | 99.69 | 933 | 99.68 |
| 9 | 1 | 120000.0 | 362.0 | 119638.0 | 99.70 | 933 | 99.68 |
| 10 | 1 | 110000.0 | 324.2 | 109675.8 | 99.71 | 933 | 99.68 |
| 11 | 1 | 100000.0 | 283.0 | 99717.0 | 99.72 | 933 | 99.68 |
| 12 | 1 | 90000.0 | 215.0 | 89785.0 | 99.76 | 934 | 99.79 |
| 13 | 1 | 80000.0 | 185.8 | 79814.2 | 99.77 | 934 | 99.79 |
| 14 | 1 | 70000.0 | 104.2 | 69895.8 | 99.85 | 934 | 99.79 |
| 15 | 1 | 60000.0 | 62.5 | 59937.5 | 99.90 | 935 | 99.89 |
| 16 | 1 | 50000.0 | 30.3 | 49969.7 | 99.94 | 935 | 99.89 |
| 17 | 1 | 40000.0 | 0.00 | 40000.0 | 100.00 | 936 | 100.00 |
|  | --- |  |  |  |  |  |  |

**The FY record YRO file table ends with a firm yield of between 47,470 and 47,480 acre-feet/year.**
(Table 3.5 on page 38 of Fundamentals Manual)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| --- |  |  |  |  |  |  |  |
| 18 | 2 | 49000.0 | 18.3 | 48981.7 | 99.96 | 935 | 99.89 |
| 19 | 2 | 48000.0 | 6.34 | 47993.7 | 99.99 | 935 | 99.89 |
| 20 | 2 | 47000.0 | 0.00 | 47000.0 | 100.00 | 936 | 100.00 |
|  | --- |  |  |  |  |  |  |
| 21 | 3 | 47900.0 | 5.14 | 47894.9 | 99.99 | 935 | 99.89 |
| 22 | 3 | 47800.0 | 3.94 | 47796.1 | 99.99 | 935 | 99.89 |
| 23 | 3 | 47700.0 | 2.75 | 47697.3 | 99.99 | 935 | 99.89 |
| 24 | 3 | 47600.0 | 1.55 | 47598.4 | 100.00 | 935 | 99.89 |
| 25 | 3 | 47500.0 | 0.35 | 47499.6 | 100.00 | 935 | 99.89 |
| 26 | 3 | 47400.0 | 0.00 | 47400.0 | 100.00 | 936 | 100.00 |
|  | --- |  |  |  |  |  |  |
| 27 | 4 | 47490.0 | 0.23 | 47489.8 | 100.00 | 935 | 99.89 |
| 28 | 4 | 47480.0 | 0.11 | 47479.9 | 100.00 | 935 | 99.89 |
| 29 | 4 | 47470.0 | 0.00 | 47470.0 | 100.00 | 936 | 100.00 |

**Seven Modules of Course on**
**Basics of Water Availability Modeling with WRAP**

1. Overview of WRAP/WAM Modeling System
2. WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records
3. Executing Programs and Managing Files and Records
4. Hydrology Features of the Modeling System
5. Simulation of Water Management
6. Simulation Model Computational Algorithms
7. **Supply Reliability, Flow and Storage Frequency, and other Analyses of Simulation Results**

**Happy Wrapping and Wamming**

## WRAP Program HYD Capabilities for Compiling, Analyzing, and Updating Hydrology Datasets

## Module 1 – Analyses of Precipitation, Evaporation, Net Evaporation-Precipitation, Stream Flow, and other Time Series

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Zachry Department of Civil and Environmental Engineering
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Sponsored by the
Texas Commission on Environmental Quality

May 2021

## Online Training Course on Program HYD Capabilities for Compiling, Analyzing, and Updating Hydrology Datasets

Module 1 – Analyses of Precipitation, Evaporation, Net Evaporation-Precipitation, Stream Flow, and Other Time Series Datasets (Hydrology Manual Chapters 1 and 2)

Module 2 – Compiling SIM Input Datasets of IN and EV Records (Hydrology Manual Chapters 3, 4, and 7)

Module 3 – Updating SIM Input Datasets of IN and EV Records (Hydrology Manual Chapters 5, 6, and 8)

## WRAP River System Hydrology, TWRI TR-431, Wurbs, Third Edition, May 2019.

Chapter 1 Introduction

Chapter 2 Compilation and Analyses of Hydrologic Time Series Data

Chapter 3 Development of Naturalized Flow and Evaporation-Precipitation Datasets

Chapter 4 SIM Input Datasets Based on Simulation Results

Chapter 5 Extension of Net Evaporation-Precipitation Rates

Chapter 6 Hydrologic Regression Model for Naturalized Flow Extension

Chapter 7 Input Records for HYD Features Described in Chapters 3 and 4

Chapter 8 Input Records for HYD Features Described in Chapters 5 and 6

## Arrays of Quantities Managed and Computationally Modified by Program HYD

Arrays for Operations of HYD Subprogram HydSeries Described in Chapter 2 (this module)

- MTS (time series identifier, year, month)
- ATS (time series identifier, year)

Arrays for HYD Operations Described in Chapters 3 through 8 (second and third modules)

- FLOW (control point, year, month)
- EP (control point, year, month)

## Water Rights Analysis Package (WRAP) Online Training Courses

1. Basics of Water Availability Modeling with the Water Rights Analysis Package
2. **WRAP Program HYD Capabilities for Compiling, Analyzing, and Updating SIM Hydrology Input Datasets**
3. Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights
4. Short-Term Conditional Reliability Modeling (CRM)
5. WRAP Daily Modeling System with Additional Features for Modeling Flood Control Reservoir Operations and Environmental Flow Standards

## Modules of Course on Basics of Water Availability Modeling with WRAP

1. Overview of WRAP/WAM Modeling System
2. WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records
3. Executing Programs and Managing Files and Records
4. **Hydrology Features of the Modeling System**
5. Simulation of Water Management
6. Simulation Model Computational Algorithms
7. Supply Reliability, Flow and Storage Frequency, and Other Analyses of Simulation Results

## WRAP Computer Programs

WinWRAP – Windows interface

- **Pre-Simulation Data Compilation**

**HYD – hydrology data for SIM**
DAY – routing parameters for SIMD
**HEC-DSSVue – time series data management**

- **River/Reservoir/Use System Simulation**

SIM – monthly simulation model
SIMD – daily simulation model
SALT – salinity tracking

- **Post-Simulation Organization of Results**

TABLES – frequency, reliability, summaries
HEC-DSSVue – data management, plots, mathematical operations, statistical analyses

## U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) Data Storage System (DSS) and HEC-DSSVue

https://www.hec.usace.army.mil/

- DSS and HEC-DSSVue are fully integrated in WRAP programs and manuals for managing time series data.
- WRAP Users Manual Chapter 6 HEC-DSS Data Storage System and HEC-DSSVue.
- HEC-DSSVue software and 465 page user's manual are available at the USACE HEC website.

## Program HYD Input Files
(Table 1.1 on Page 8 of Hydrology Manual)

Root1.HIN – Specifications for operations to be performed.
Root1.DSS – Time series input data in DSS format.
Root1.FLO – Stream flows on IN records.
Root1.EVA – Evaporation less precipitation depths on EV records.
Root1.HYD – IN and EV records in a single text file.
Root1.DIS – Flow distribution FD, FC, and WP records.
Root1.OUT – SIM simulation results output OUT file.
Precipitation.PPP – TWDB statewide quadrangle monthly precipitation.
Evaporation.EEE – TWDB statewide monthly reservoir evaporation.
PrecipEvap.DSS – TWDB precipitation and evaporation in DSS format.

## Program HYD Output Files
(Table 1.1 on Page 8 of Hydrology Manual)

Root2.HMS – Traces and error and warning messages.
Root2.FLO – Stream flows on IN records.
Root2.EVA – Evaporation less precipitation depths on EV records.
Root2.TSF – Monthly time series of any variable.
Root2.DSS – Time series output data in DSS format.
Root2.HOT – Statistical analysis results for options in Chapter 2. All output not contained in other output files for features covered in Chapters 3 through 8.

## River System Hydrology

- The WRAP program HYD and HEC-DSSVue provide flexible sets of tools for developing monthly naturalized flows (*IN* records) and evaporation less (optionally adjusted) precipitation rates (*EV*) records.
- Observed flows are available from the U.S. Geological Survey (USGS) National Water Information System (NWIS) website and other sources.
- Monthly evaporation and precipitation data are available from Texas Water Development Board (TWDB) databases and other sources.

## Naturalized Stream Flow

Naturalized flows input on *IN* records in a DSS or FLO file are a *homogeneous* time series of monthly flows in a SIM simulation input dataset that do not include effects of the water development, management, and use that are to be simulated in the SIM simulation.

*Stationarity* (homogeneity over time) – flows represent a uniform condition of river basin and water resources development, long-term climate, and water use.

## Net Reservoir Evaporation Less Precipitation

- Evaporation from and precipitation falling on the reservoir water surface are combined as net evaporation minus precipitation. To prevent “double-accounting”, precipitation may be adjusted approximately for runoff from the reservoir site that is contained in the naturalized stream flows.
- Net evaporation-precipitation rates are recorded on *EV* records in a EVA file or DSS file in units of feet/month.
- SIM uses net evaporation-precipitation depths, along with a calculation of reservoir surface area, to determine the volume of water lost or gained due to the evaporation from and adjusted precipitation on the reservoir water surface.

## Hydrology Manual Chapter 2
## Compilation and Analyses of Hydrologic Time Series Data

The HYD subprogram HydSeries provides routines for compiling, managing, and analyzing time series data that include:

- Reading monthly time series data in alternative formats that include DSS, FLO, or EVA files, columns in tables, and TWDB evaporation and precipitation datasets.
- Storing the time series in alternative file and organizational formats.
- Developing annual series of totals or means and annual series of minima or maxima of moving averages.
- Computing basic statistics for the monthly data and annual totals.
- Linear trend regression analyses of monthly or annual time series.

### **Hydrologic Series HS Record in HYD Input HIN File** (Pages 12-15)

YRBEG and YREND – beginning and ending year

INFILE – format options or text or DSS input file with time series

OUTFILE - format options or text or DSS output file with time series

INEXT – filename extension for the time series input file

OUTEXT – filename extension for the time series output file

INID and OUTID – optional identifiers for data in input and output files

PE – net evaporation-precipitation, evaporation, or precipitation

SSI – identifiers on SI records, all 92 quads, or all 168 quads

STAT – basic statistics, linear trend analysis, 12 monthly & annual means

SERIES – monthly, annual totals or means, annual minima or maxima of moving averages for MA months

MX – multiplier factor

### **Texas Water Development Board (TWDB) Database of Monthly Quadrangle Precipitation and Evaporation Depths**

https://waterdatafortexas.org/lake-evaporation-rainfall

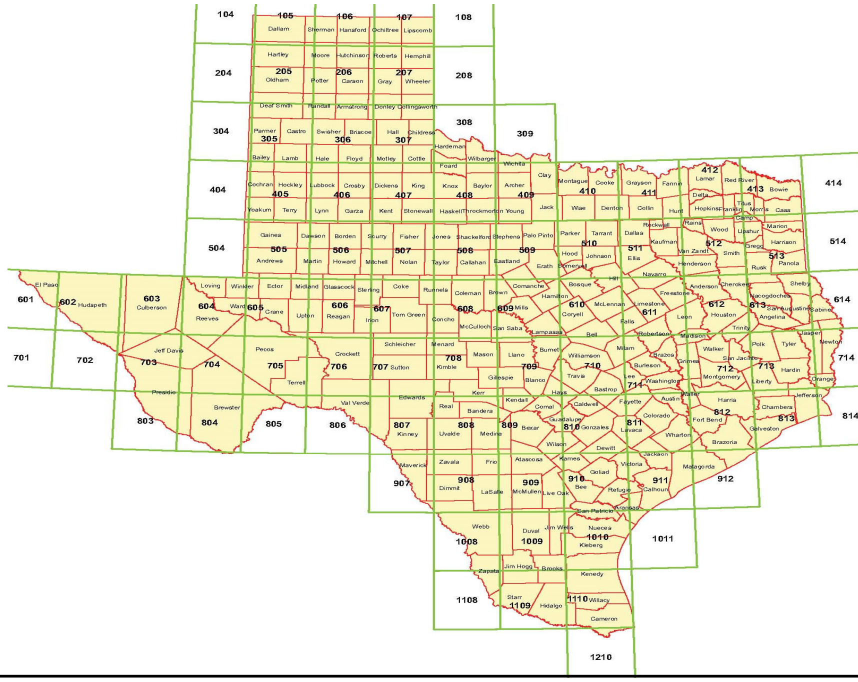
HYD Input Data Files with TWDB Datasets

Precipitation.PPP – TWDB monthly precipitation.

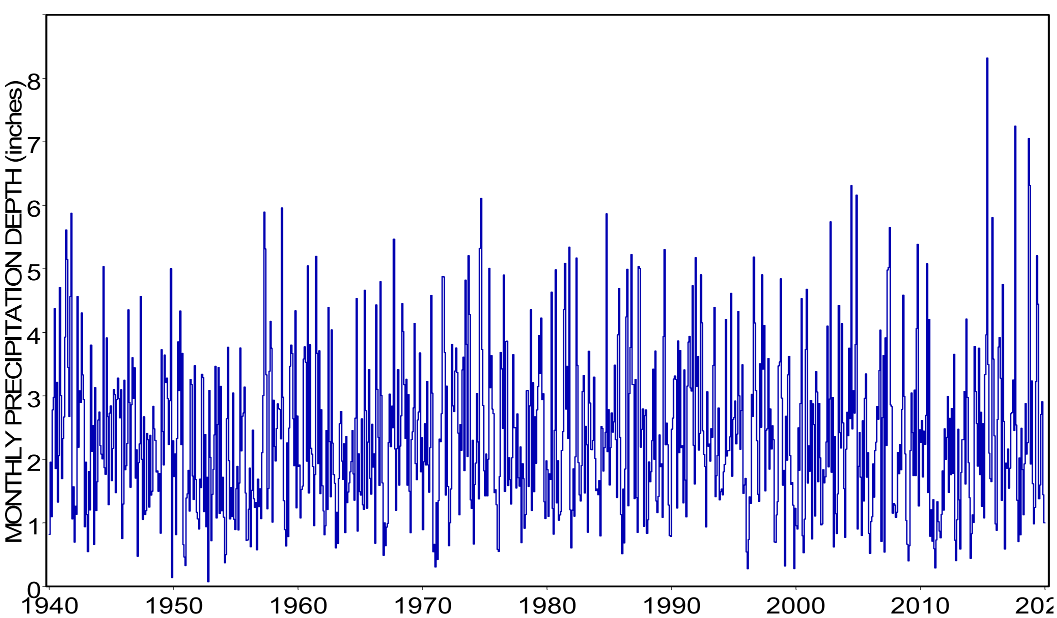
Evaporation.EEE – TWDB monthly reservoir evaporation.

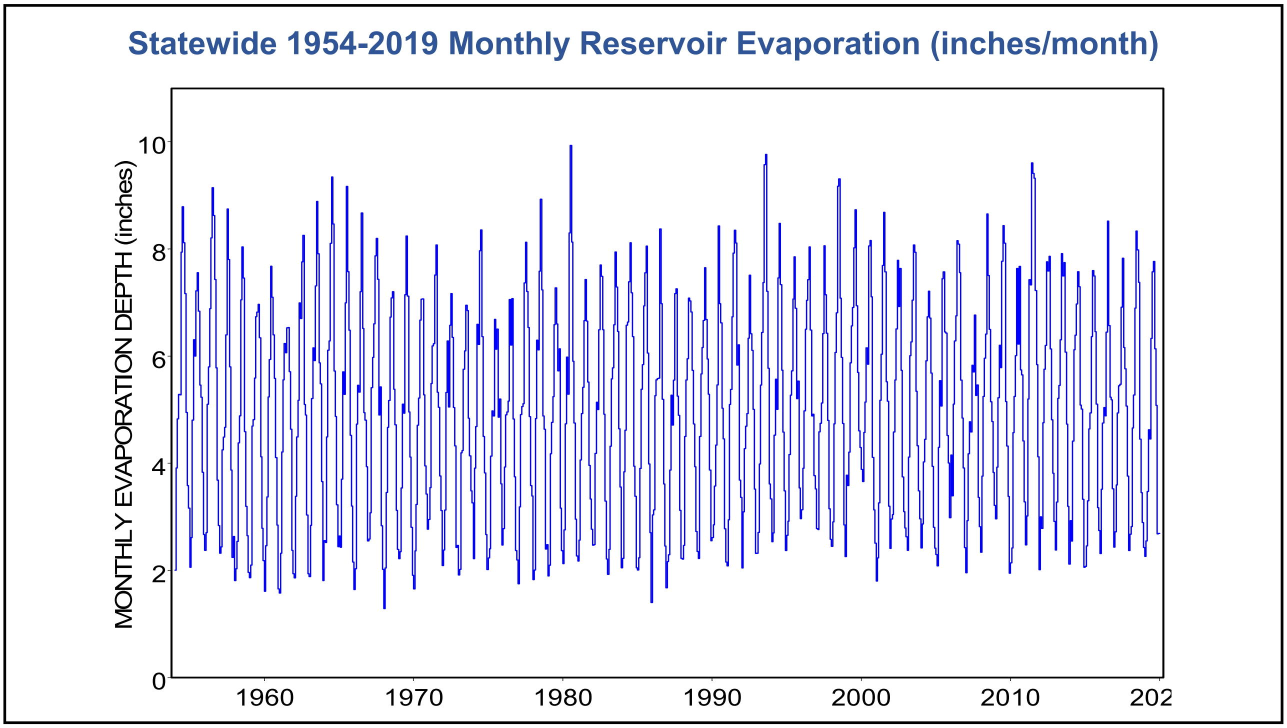
PrecipEvap.DSS – TWDB precipitation and evaporation in DSS format.

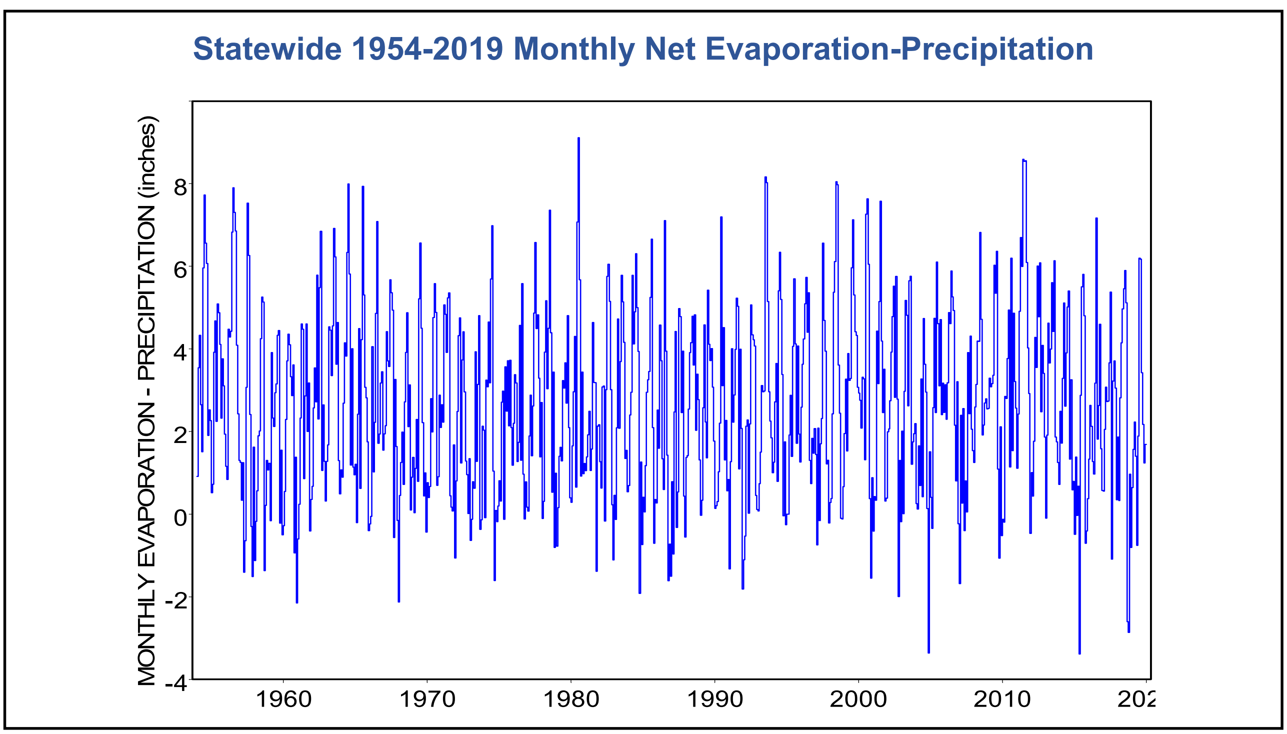
**TWDB Evaporation and Precipitation Data Quadrangle Map (Figure 2.1 Page 20)**



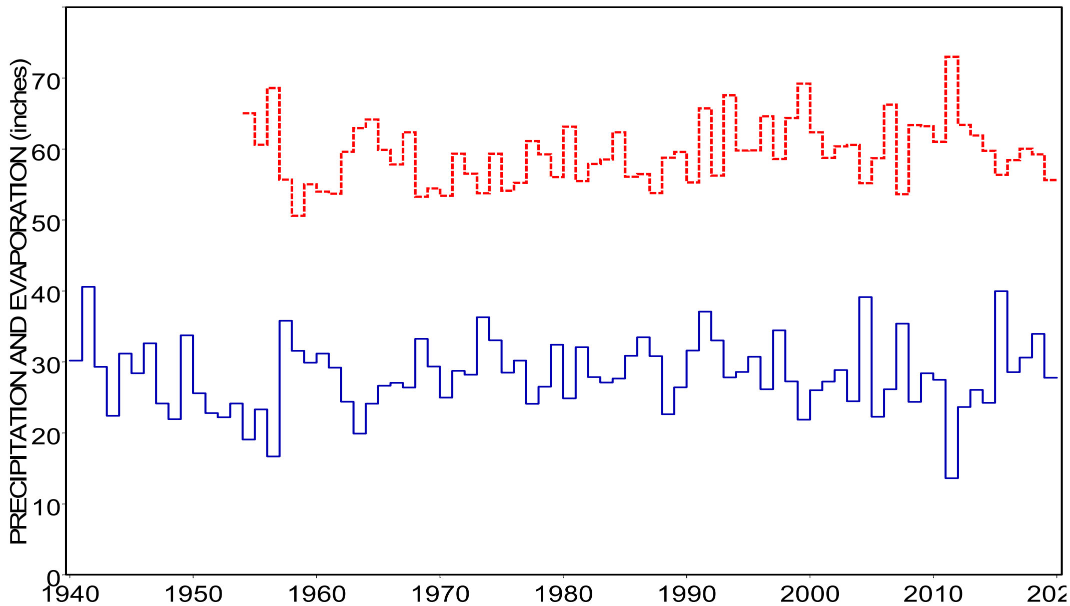
**Statewide 1940-2019 Monthly Precipitation (inches/month)**



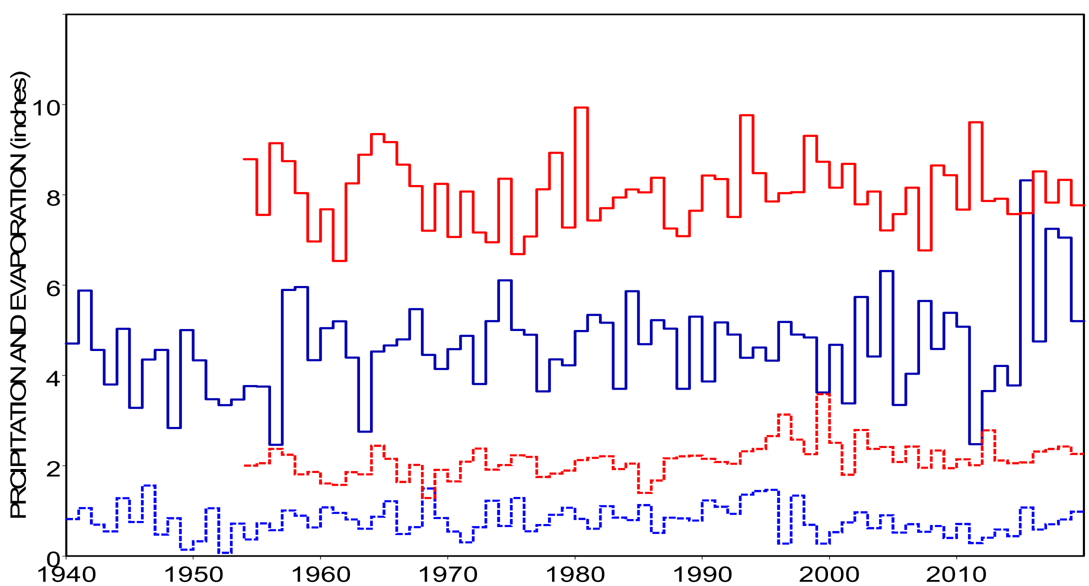

Statewide 1954-2019 Monthly Reservoir Evaporation (inches/month)
MONTHLY EVAPORATION DEPTH (inches)
0
2
4
6
8
10
1960
1970
1980
1990
2000
2010
202


Statewide 1954-2019 Monthly Net Evaporation-Precipitation
MONTHLY EVAPORATION - PRECIPITATION (inches)
-4
-2
0
2
4
6
8
1960
1970
1980
1990
2000
2010
202

**Statewide Annual Precipitation and Reservoir Evaporation (inches/year)**




**Statewide Average of Annual Maximum and Minimum Monthly Precipitation and Reservoir Evaporation (inches/month)**



## Table 2.7 Linear Regression Results (Page 30)

| Variable | Mean (inches) | Intercept (inches) | Slope (inches per month or year) | Intercept (% mean) | Slope (% mean) |
|---|---|---|---|---|---|
| monthly precipitation | 2.3441 | 2.2941 | 0.00010531 | 97.8682 | 0.00449 |
| annual precipitation | 28.1293 | 27.5587 | 0.01426439 | 97.9716 | 0.05071 |
| minimum 2-month | 2.1302 | 2.2687 | -0.00346126 | 106.4994 | -0.16249 |
| maximum 2-month | 7.8263 | 7.0764 | 0.01874692 | 90.4184 | 0.23954 |
| | | | | | |
| monthly evaporation | 4.9537 | 4.7756 | 0.00045617 | 96.4040 | 0.00921 |
| annual evaporation | 59.4444 | 57.3302 | 0.06406738 | 96.4434 | 0.10778 |
| minimum 2-month | 4.5457 | 3.9507 | 0.01803074 | 86.9105 | 0.39665 |
| maximum 2-month | 15.4652 | 15.4130 | 0.00158250 | 99.6623 | 0.01023 |

## Table 2.8 Number of Positive and Negative Regression Slopes for Individual Quads

| Variable | Number of slopes that are | |
|---|---|---|
| | Positive | Negative |
| Statewide Monthly Precipitation | 66 | 26 |
| Statewide Annual Precipitation | 65 | 27 |
| Annual Two-Month Minimum | 24 | 68 |
| Annual Two-Month Maximum | 74 | 18 |
| Statewide Monthly Evaporation | 63 | 29 |
| Statewide Annual Evaporation | 63 | 29 |
| Annual Two-Month Minimum | 84 | 8 |
| Annual Two-Month Maximum | 51 | 41 |

## U.S. Geological Survey (USGS)
## National Water Information System (NWIS)

https://waterdata.usgs.gov/nwis

https://waterdata.usgs.gov/tx/nwis/nwis

**Figure 2.8 Mean Daily Flows in cfs at USGS Gage on Brazos River at Waco during October 1898 – January 2019**

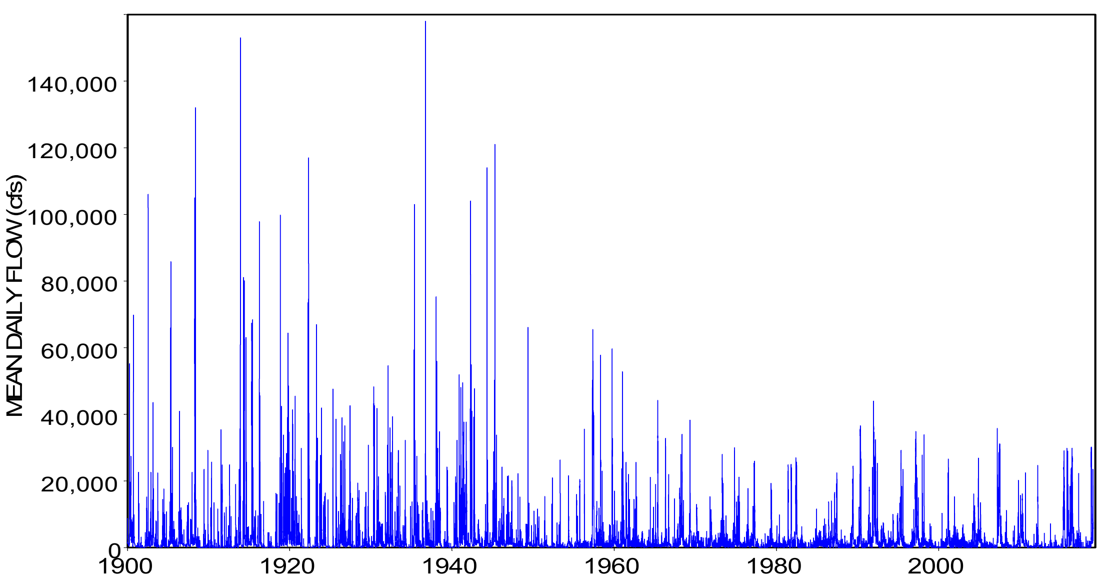


**Figure 2.9 Mean Monthly Flows in cfs at USGS Gage on Brazos River at Waco during October 1898 – December 2018**

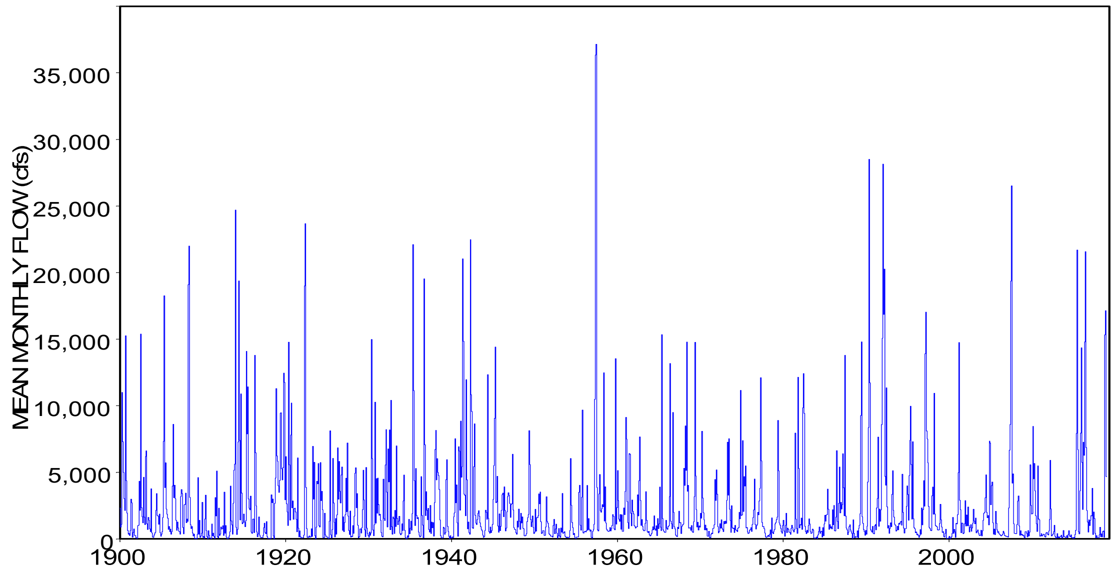
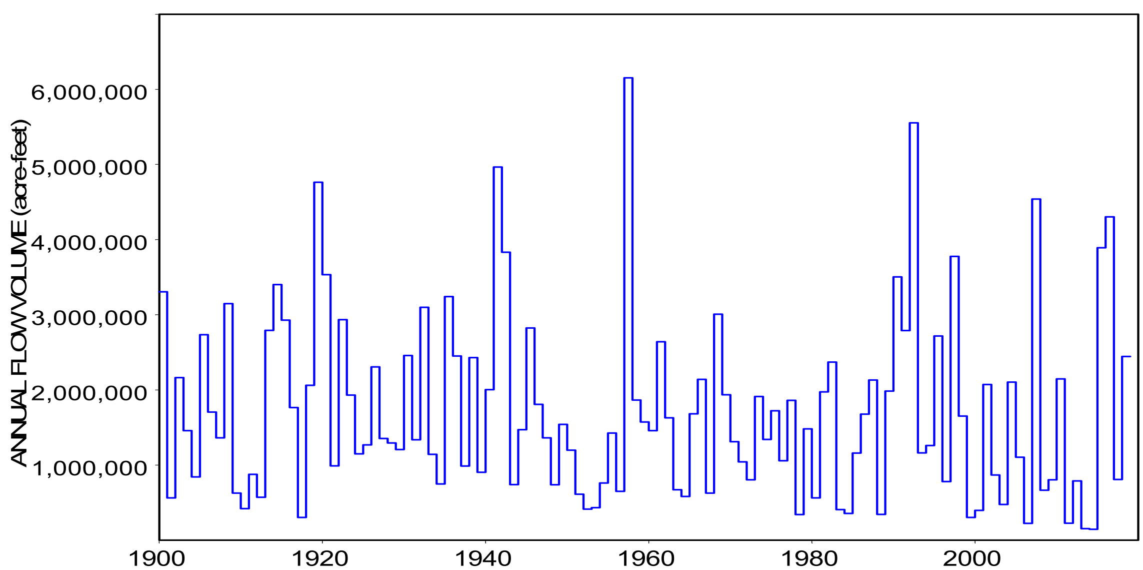
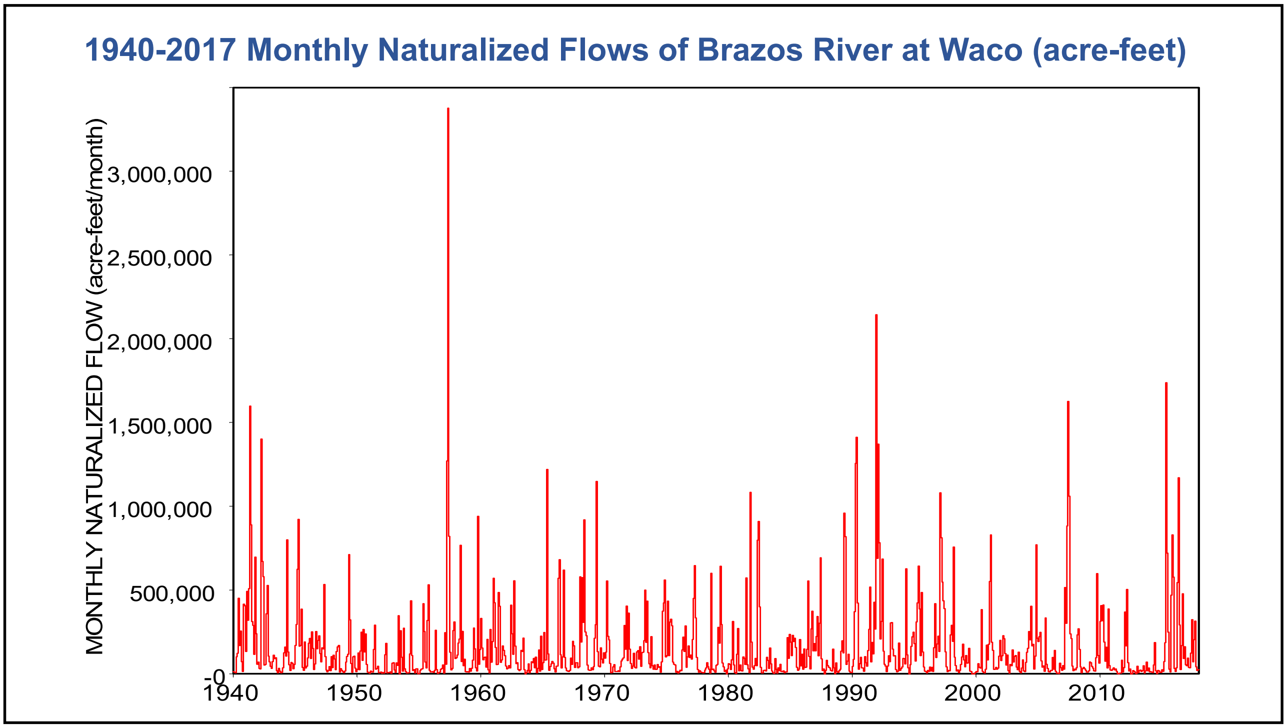
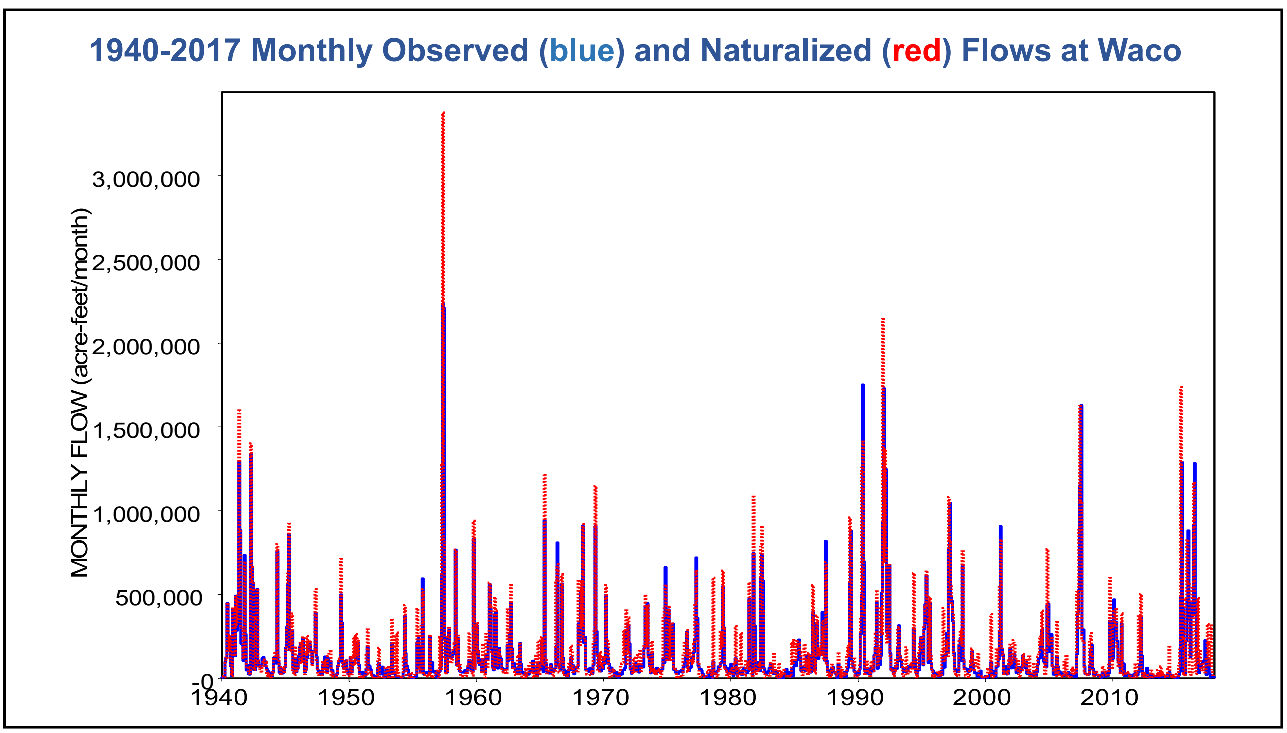


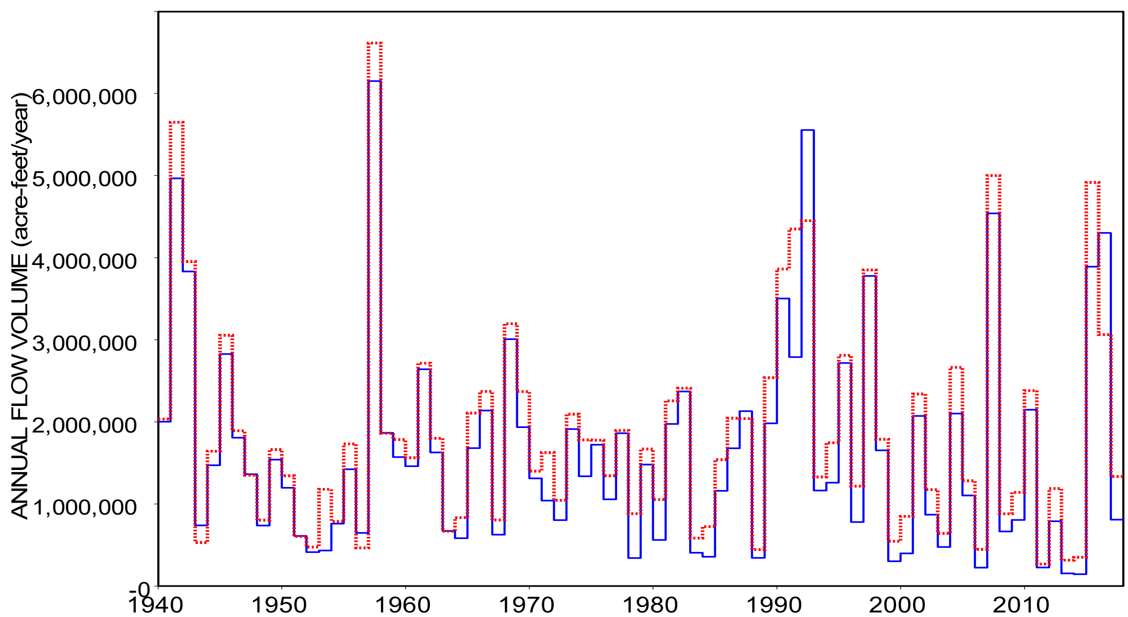

**Figure 2.10 Annual Flows in acre-feet at the Gage on the Brazos River at Waco**




1940-2017 Monthly Naturalized Flows of Brazos River at Waco (acre-feet)
MONTHLY NATURALIZED FLOW (acre-feet/month)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
-0
1940
1950
1960
1970
1980
1990
2000
2010


1940-2017 Monthly Observed (blue) and Naturalized (red) Flows at Waco
MONTHLY FLOW (acre-feet/month)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
-0
1940
1950
1960
1970
1980
1990
2000
2010

**1940-2017 Annual Observed (blue) and Naturalized (red) Flows at Waco**




## Table 2.13 (Page 44)
## HYD Input HIN File with STAT Option 1 and Series Option 1

```
HS  1940    2017   4   0          IN       0   0   1   1
SI     2     NAT    USGS
ED
```

## Table 2.14 (Page 45)
## HYD Output HOT File with STAT Option 1 and Series Option 1

**HYD Output HOT File**

**Monthly Statistics (STAT=1)**

| Site | Mean | Stand Dev | Minimum | Maximum |
|---|---|---|---|---|
| NAT | 155102.4 | 258754.1 | 0.0 | 3376485.0 |
| USGS | 136515.2 | 231853.1 | 1608.6 | 2234181.8 |

## Table 2.15 (Page 45)
## HYD Output HOT File with STAT Option 2 and Series Option 1

**HYD Output HOT File**

**Linear Regression Analysis (STAT=2)**

**Regression Coefficients for Monthly Series**

| Site | Mean | Intercept | Slope | Intercept % Mean | Slope % Mean |
|---|---|---|---|---|---|
| NAT | 155102.4 | 161985.8 | -14.692397 | 104.4380 | -0.00947 |
| USGS | 136515.2 | 147947.5 | -24.401993 | 108.3744 | -0.01787 |
| Averages | 145808.8 | 154966.7 | -19.547195 | 106.4062 | -0.01367 |

## Table 2.16 (Page 45)
## HYD Output HOT File with STAT Option 3 and Series Option 1

HYD OUTPUT HOT FILE

Monthly and Annual Means for Each Time Series (STAT=3)

| Site | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAT | 90907.6 | 134931.9 | 173469.1 | 205193.3 | 383300.1 | 253055.3 | 101592.6 | 71346.1 | 100172.9 | 148305.7 | 93259.1 | 105694.5 | 1861228.2 |
| USGS | 103275.9 | 112152.6 | 158021.0 | 159959.9 | 294039.4 | 260454.0 | 120432.6 | 67657.9 | 71519.6 | 105205.5 | 86527.5 | 98935.7 | 1638182.6 |

## Summary of Time Series Analysis Capabilities Documented by Chapter 2 of the Hydrology Manual

- Conversions between file formats including DSS and alternative text file organizational formats.
- Efficient access to TWDB precipitation and evaporation databases.
- Computation of annual series from the daily monthly series that may be annual totals or means or minima or maxima of monthly moving averages in each year.
- Computation of basic statistics for the time series datasets.
- Linear regression trend analysis.

## WRAP Program HYD Capabilities for Compiling, Analyzing, and Updating Hydrology Datasets

## Module 2
## Compiling SIM Input Datasets of IN and EV Records

Ralph Wurbs, Ph.D., P.E., Professor
Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the
Texas Commission on Environmental Quality

May 2021

## Online Training Course on Program HYD Capabilities for Compiling, Analyzing, and Updating Hydrology Datasets

Module 1 – Analyses of Precipitation, Evaporation, Net Evaporation-Precipitation, Stream Flow, and Other Time Series Datasets
(Hydrology Manual Chapters 1 and 2)

**Module 2 – Compiling SIM Input Datasets of IN and EV Records**
**(Hydrology Manual Chapters 3, 4, and 7)**

Module 3 – Updating SIM Input Datasets of IN and EV Records
(Hydrology Manual Chapters 5, 6, and 8)

## Modules of Course on Basics of Water Availability Modeling with WRAP

1. Overview of WRAP/WAM Modeling System
2. WinWRAP, SIM, TABLES, and HEC-DSSVue Programs, Input and Output Files, and Data Records
3. Executing Programs and Managing Files and Records
4. **Hydrology Features of the Modeling System**
5. Simulation of Water Management
6. Simulation Model Computational Algorithms
7. Supply Reliability, Flow and Storage Frequency, and Other Analyses of Simulation Results

## River System Hydrology

- The WRAP program HYD and HEC-DSSVue provide flexible sets of tools for developing monthly naturalized flows (*IN* records) and evaporation less (optionally adjusted) precipitation rates (*EV*) records.
- Observed flows are available from the U.S. Geological Survey (USGS) National Water Information System (NWIS) website and other sources.
- Monthly evaporation and precipitation data are available from Texas Water Development Board (TWDB) databases and other sources.

## Naturalized Stream Flow

Naturalized flows input on *IN* records in a FLO or DSS file are a *homogeneous* time series of monthly flows in a SIM simulation input dataset that do not include effects of the water development, management, and use that are to be simulated in the SIM simulation.

*Stationarity* (homogeneity over time) – flows represent a uniform condition of river basin and water resources development, long-term climate, and water use.

## Net Reservoir Evaporation Less Precipitation

- Evaporation from and precipitation falling directly on the reservoir water surface are combined as net evaporation minus precipitation.
- Net evaporation-precipitation rates in units of feet/month are recorded on *EV* records in a EVA or DSS file.
- SIM uses net evaporation-precipitation depths, along with a calculation of reservoir surface area, to determine the volume of water lost or gained due to the evaporation from and adjusted precipitation on the reservoir water surface.

## Precipitation Adjustments

Options are available to prevent "double counting" the portion of the precipitation falling on a reservoir water surface that is also included in naturalized stream flow inflow to the reservoir.

SIM JD record EPADJ and CP record EWA
SIM FD and WP record watershed area
HYD EP record

(Reference Manual, Chapter 3, pages 46-47)

(Hydrology Manual, Chapter 3, page 54)

## WRAP River System Hydrology, TWRI TR-431, Wurbs, Third Edition, May 2019.

Chapter 1 Introduction

Chapter 2 Compilation and Analyses of Hydrologic Time Series Data

**Chapter 3 Development of Naturalized Flow and Evaporation-Precipitation Datasets**

**Chapter 4 SIM Input Datasets Based on Simulation Results**

Chapter 5 Extension of Net Evaporation-Precipitation Rates

Chapter 6 Hydrologic Regression Model for Naturalized Flow Extension

**Chapter 7 Input Records for HYD Features Described in Chapters 3 and 4**

Chapter 8 Input Records for HYD Features Described in Chapters 5 and 6

## Chapter 3 of Hydrology Manual
## Development of Naturalized Stream Flow and Net Evaporation-Precipitation Datasets

- Initial manipulations of monthly streamflow volumes and net evaporation-precipitation depths.
- Annual streamflow volumes and evaporation-precipitation depths.
- Develop sets of EV record net evaporation-precipitation depths.
- Develop sets of IN record monthly naturalized or otherwise adjusted streamflow volumes.
- Changing the organization and format of the datasets.

## Arrays of Monthly Quantities Managed and Computationally Modified by Program HYD as Described in Hydrology Manual Chapter 3

**FLOW (control point, year, month)**
**EP (control point, year, month)**

The FLOW array is initially populated with observed flows read from an input file that are then converted through a series of adjustments to naturalized flows recorded in an output file as IN records.

The EP array stores evaporation less precipitation depths developed by HYD operations and recorded in an output file as EV records.

## Features Described in Chapter 3 for Developing Monthly Naturalized Flow Datasets (IN Records)

- Adding or subtracting sets of adjustments to stream flows with the flow adjustments being obtained from various sources and optionally cascading downstream optionally with channel losses.
- Stream flow adjustments for the effects of reservoirs.
- Applying a regression equation: $Q_{adjusted} = a\,Q^{b} + c$
- Distributing flows from gaged (known flow) to ungaged (unknown flow) locations.
- Adjusting stream flows to prevent incremental flows from being negative.

## Stream Flow Naturalization and Distribution

Naturalized flows at primary control points recorded on *IN* records in a DSS or FLO file are developed by adjusting gaged flows to remove the effects of upstream water resources development, management, and use occurring during the past period-of-record.

- Reservoir construction and operation (all WAMs)
- Diversions and return flows (all WAMs)
- Land use changes (possibly)
- Pumping of aquifers which alter spring flows (some WAMs)

Naturalized flows at secondary control points are computed during the simulation based on flows at primary control points and parameters recorded in the flow distribution DIS file.

## Adjustments to Gaged Flows

naturalized flow = gaged flow
+ upstream diversions
− upstream return flows
+ change in upstream reservoir storage
+ upstream reservoir net evaporation-precipitation

## Input Records in HYD Input HIN File

(Chapter 7 Input Records for HYD Features
Described in Chapters 3 and 4)

JC – job control (Red denotes records used only by HYD.)
XL – multiplier factors (Black denotes both SIM and HYD.)
CP – control point information
MF – monthly factors
CI – constant inflows
SV and SA – reservoir storage volume and surface area
EP – evaporation-precipitation combining operations
AS – stream flow adjustment specification
RS – adjustments to stream flow for upstream reservoirs

## Input Records in Other HYD Input Files

(Chapter 7 Input Records for HYD Features
Described in Chapters 3 and 4)

IN – monthly stream flow volumes at a control point
EV – monthly evaporation, precipitation, or net evap-precip depths
FA – flow adjustments
SC – reservoir storage contents
FD – flow distribution
WP – watershed parameters

## Features Described in Chapter 3 for Developing Evaporation-Precipitation Datasets (EV Records)

Applications of the HYD EP record mathematical operations on arrays of time series quantities include:

- Subtracting monthly precipitation depths from evaporation depths to obtain EV record evaporation-precipitation depths. Precipitation depths may be adjusted by multiplying by a factor or applying a regression equation.
- Developing net evaporation-precipitation depths for a particular control point as a weighted average of values from multiple locations.

## EP Array Arithmetic Manipulations Controlled by EP Records in HIN File

EP (control point, year, month)

The EP array stores changing evaporation, precipitation, or net evaporation less precipitation depths developed by HYD operations and finally recorded in an output file as EV records.

Evaporation-precipitation combining operations are specified on EP records.

## Chapter 4 of Hydrology Manual SIM Input Datasets Based on SIM Simulation Results

(Output Input OI Input Record in HIN File)

Applications

1. Developing a condensed SIM input dataset of IN record stream flows for a defined water management system.
2. Extending naturalized stream flows.
3. Other applications.

## Case Study of Extending Naturalized Flows and Developing Condensed Dataset

R.A. Wurbs and T.J. Kim, *Extending and Condensing the Brazos River Basin Water Availability Model*, TWRI TR-340, 491 pages, December 2008.

R.A. Wurbs and T.J. Kim, "Condensing Water Availability Models to Focus on Specific Water Management Systems," *Texas Water Journal*, TWRI, 1(1):20-32, September 2010.

## Online Training Course on Program HYD Capabilities for Compiling, Analyzing, and Updating Hydrology Datasets

Module 1 – Analyses of Precipitation, Evaporation, Net Evaporation-Precipitation, Stream Flow, and Other Time Series Datasets (Hydrology Manual Chapters 1 and 2)

Module 2 – Compiling SIM Input Datasets of IN and EV Records (Hydrology Manual Chapters 3, 4, and 7)

Module 3 – Updating SIM Input Datasets of IN and EV Records (Hydrology Manual Chapters 5, 6, and 8)

## WRAP Program HYD Capabilities for Compiling, Analyzing, and Updating Hydrology Datasets

## Module 3
## Updating SIM Input Datasets of IN and EV Records

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Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the
Texas Commission on Environmental Quality

May 2021

## Online Training Course on Program HYD Capabilities for Compiling, Analyzing, and Updating Hydrology Datasets

Module 1 – Analyses of Precipitation, Evaporation, Net Evaporation-Precipitation, Stream Flow, and Other Time Series Datasets
(Hydrology Manual Chapters 1 and 2)

Module 2 – Compiling SIM Input Datasets of IN and EV Records
(Hydrology Manual Chapters 3, 4, and 7)

**Module 3 – Updating SIM Input Datasets of IN and EV Records
(Hydrology Manual Chapters 5, 6, and 8)**

## IN Record Naturalized Stream Flow

Naturalized flows input on *IN* records in a DSS or FLO file are time series of monthly flows in a SIM or SIMD simulation input dataset that do not include the effects of the water development, management, and use that are to be simulated in the SIM simulation. IN record stream flows are commonly viewed as representing natural conditions without human development.

## EV Records of Net Monthly Reservoir Evaporation Less Precipitation Depths

Evaporation from and precipitation falling directly on the reservoir water surface are combined as net evaporation minus precipitation.

Precipitation may be adjusted to reflect naturalized flows containing runoff from the portion of the watershed covered by the reservoir.

Net evaporation less precipitation depths are recorded on *EV* records in a DSS or EVA file in units of feet/month.

**Extending (Updating) Datasets of Monthly Naturalized Flows (IN Records) and Net Evaporation Less Precipitation Depths (EV Records) Employing the TWDB Annually Updated Databases of Monthly Quadrangle Precipitation and Evaporation Depths**

Chapter 5 Extension of Net Evaporation-Precipitation Rates

Chapter 6 Hydrologic Regression Model for Naturalized Flow Extensions

Chapter 8 Input Records for HYD Features Described in Chapters 5 and 6

**Texas Water Development Board (TWDB) Database of Monthly Quadrangle Precipitation and Evaporation Depths**

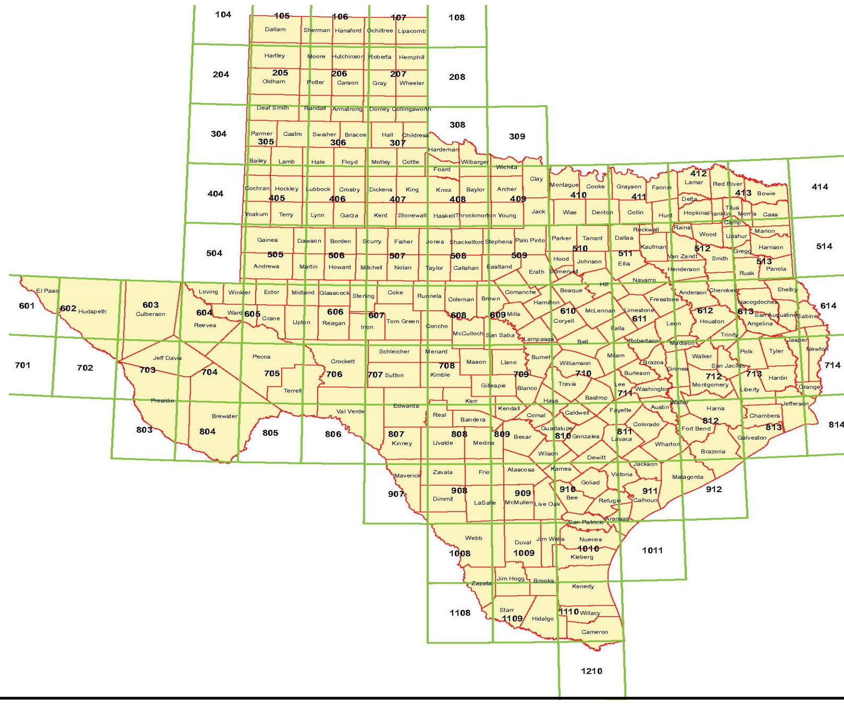
https://waterdatafortexas.org/lake-evaporation-rainfall

HYD Input Data Files with TWDB Datasets

Precipitation.PPP – TWDB monthly precipitation.

Evaporation.EEE – TWDB monthly reservoir evaporation.

PrecipEvap.DSS – TWDB precipitation and evaporation in DSS format.



## Chapter 5 of Hydrology Manual

### Extension of Net Evaporation-Precipitation Rates

Operations include:

- Managing datasets of monthly reservoir evaporation, precipitation, and net evaporation-precipitation depths.
- Computing weighted averages for data from multiple quads.
- Subtracting precipitation depths from evaporation depths.
- Subtracting adjusted precipitation depths from evaporation depths.
- Computing basic statistics for general information.

## Chapter 6 of Hydrology Manual

### Hydrologic Regression Model for Naturalized Flow Extensions

The physically based regression model relates monthly naturalized stream flow volumes to monthly precipitation and evaporation depths from the TWDB quadrangle-based datasets. A model is developed for each primary control point.

The model has many parameters that are determined by a structured calibration process based on relating naturalized flows to precipitation and evaporation depths during the period of known naturalized flows.

The calibrated model is applied with known precipitation and evaporation to estimate naturalized flows for the extension period.

### Conceptualization of Basin Watershed Volume Budget

stream flow = base flow + precipitation – losses

$$Q_T = B_T + P_T - L_T + (P_{T-1} - L_{T-1})$$

$$\text{where } L = aP^b + cE$$

Base flow B and precipitation P represent the sources of stream flow Q at the watershed outlet. A portion of the precipitation falling this month reaches the watershed outlet as stream flow this month, a portion contributes to flow next month, and the remainder is lost to hydrologic abstractions. The portions of $P_T$ in month T that do not contribute to $Q_T$ and $Q_{T+1}$ include losses due to evapotranspiration, overland infiltration, stream seepage, and storage. These losses L are viewed as a function of precipitation P and evaporation E.

## Conceptualization of Monthly Naturalized Flow Model

The naturalized flow Q(t) for month t is computed as a function of the summation of runoff RP(t) from precipitation in each upstream quadrangle (i) plus a base flow component BF(t).

The runoff component of naturalized flow from each relevant quadrangle (i) is computed as a function of precipitation P(i,t) and evaporation E(i,t) in the current month and precipitation PP(I,t-1) that did not become stream flow in the preceding month (t-1).

## Hydrologic Regression Model (Page 112)

$$Q(t) = U(1) \times RP(t)^{U(2)} + BF(t) \qquad (1)$$

$$RP(t) = \sum_{i=1}^{N} \left[ P(i,t) - X(i,1) \times P(i,t)^{X(i,2)} - X(i,3) \times E(i,t) + PP(i,t\text{-}1) - X(i,4) \times PP(i,t\text{-}1)^{X(i,5)} \right] \qquad (2)$$

$$PP(i,t) = X(i,1) \times P(i,t)^{X(1,2)} \qquad (3)$$

$$BF(t) = B(m) \times DI(t) \times BX(z) \quad \text{where } DI(t) \text{ is the lesser of} \qquad (4)$$

$$DI(t) = 1.0 \text{ or } DI(t) = DX \left[ \left( \frac{\bar{E}(m\text{-}1) + \bar{E}(m)}{\bar{P}(m\text{-}1) + \bar{P}(m)} \right) \frac{\sum P(i,t\text{-}1) + P(i,t)}{\sum E(i,t\text{-}1) + E(i,t)} \right]^2 \qquad (5)$$

## Variables Other Than Calibration Parameters (Page 112)

Q(t) computed naturalized flow volume for month t which may consist of the weighted average of the Q(t,z) computed for two adjacent overlapping flow zones if flows are categorized by zones (acre-feet/month)

Q(t,z) naturalized flow computed for either low flow (z=1), medium flow (z=2), high flow (z=3), or flood flow (z=4) zones during month t (acre-feet/month)

RP(t) summation of runoff from individual quadrangles in current month t resulting from precipitation in the current month t and/or preceding month t-1 (acre-feet/month)

BF(m,z) base flow in each of the 12 months of the year that may reflect precipitation falling long before as well as during months t and t-1 (acre-feet/month)

U(k) dimensionless multiplier and exponent coefficients (0.0≤U(1)≤1.0 and 0.7≥U(2))

N number of quadrangles included in the watershed (i = 1, 2, 3, . . . , N)

P(i,t) precipitation during month t in quadrangle i (acre-feet/month)

PP(i,t) portion of precipitation in month t not contributing to Q(t) and becoming stream flow in the next month and/or hydrologic abstractions (acre-feet/month)

E(i,t) maximum potential evapotranspiration volume estimated based on reservoir surface evaporation rates during the month t in quadrangle i (acre-feet/month)

X(i,j,z) model parameters consisting of 5N dimensionless coefficients (j = 1, 2, 3, 4, 5) that may vary between zones (z = 1, 2, 3, 4) that have values ranging between 0.0 and 1.0

B(m,z) base flow parameters for the 12 months (m = 1, 2, 3, ..., 12) of the year (ac-ft/month)

DI(t) dimensionless drought index that varies from 1.0 to 0.0 each month depending on the ratio of precipitation to evaporation volume during the current and preceding months

BX(z) dimensionless multiplier factor in the base flow term entered on the *UB* record with a default of 1.0 (z = 1, 2, 3, 4 for low, medium, high, and flood flow zones)

DX dimensionless multiplier factor entered on the *FE* record with a default of 1.0

$\overline{P}(m)$ monthly means of precipitation volumes for each of the m = 1, 2, 3, ..., 12 months of the year for specified quadrangles (acre-feet/month)

$\overline{E}(m)$ monthly means of evaporation volumes for each of the m = 1, 2, 3, ..., 12 months of the year for specified quadrangles (acre-feet/month)

## 4(13+5N)+3 Calibration Parameters

(N is the number of quadrangles.)

B(m,z) - base flow (ac-ft/month) for each month of the year (month m = 1 to 12 and flow zone z = 1 to 4)

BX(z) - dimensionless multiplier factor ranging between 0.0 and 1.0, with a default of 1.0, contained in the base flow term for low, medium, high, and flood flows

DX - drought index multiplier factor with a default of 1.0

X(i,j,z) - five dimensionless rainfall-runoff parameters (j=1,2,3,4,5) for each quadrangle (i = 1 to N) located in the watershed that range between 0.0 and 1.0

U(1) and U(2) - two dimensionless parameters modeling nonlinear relationship between total rainfall and runoff which are constrained to 0.0≤U(1)≤1.0 and 0.7≥U(2).

## Two-Level Calibration Process

1. The first level is an optimization-based automated calibration process composed of algorithms for determining the values for the parameters U(1), U(2), B(m,z), BX(z), DX, and X(i,j,z) of the hydrologic model. The objective is to develop a calibrated model that reproduces the known original naturalized flows from the WAM dataset as closely as possible as measured by the objective function criteria.

2. The second level consists of comparative analyses of flows computed with the model calibrated in level 1 versus known flows to derive a set of multiplier factors designed primarily to improve the accuracy of the model in reproducing the statistical characteristics of the original naturalized flows. The primary goal is to reproduce the mean, standard deviation, and flow frequency curve as closely as possible.

## Objective Function (Page 118)

| | low flows | medium | high | flood flows |
|---|---|---|---|---|
| OF = | W1×Z1 + | W2×Z2 + | W3×Z3 + | W4×Z4 + |
| | W5×Z5 + | W6×Z6 + | W7×Z7 + | W8×Z8 + |
| | W9×Z9 + | W10×Z10 + | W11×Z11 + | Z12×Z12 + |
| | W13×Z13 + | W14×Z14 + | W15×Z15 + | W16×Z16 |

$$Z1 = Z2 = Z3 = Z4 = \left(\frac{1}{K}\right)\sum_{t=1}^{K}\left(\frac{100 \times \left|Q(t)_{known} - Q(t)_{computed}\right|}{\overline{Q(t)}_{known}}\right)^{E1}$$

$$Z5 = Z6 = Z7 = Z8 = \left(\frac{1}{K}\right)\sum_{t=1}^{K}\left(\frac{100 \times \left|Q(t)_{known} - Q(t)_{computed}\right|}{ZZZ}\right)^{E1}$$

where ZZZ is the greater of $Q(t)_{known}$ or $Q(t)_{computed}$

$$Z9 = Z10 = Z11 = Z12 = \left|N_K - N_C\right|^{E1}$$

$$Z13 = Z14 = Z15 = Z16 = \left(\frac{1}{K}\right)\frac{\left(100 \times \left|\sum_{t=1}^{K} Q(t)_{known} - \sum_{t=1}^{K} Q(t)_{computed}\right|\right)^{E2}}{\overline{Q}_{known}}$$

## **Univariate Gradient Search Algorithm** (Page 122)

$$x^* = x - \frac{f'(x)}{f''(x)}$$

$$f'(x) = \frac{f(x+\Delta x) - f(x-\Delta x)}{2\Delta x}$$

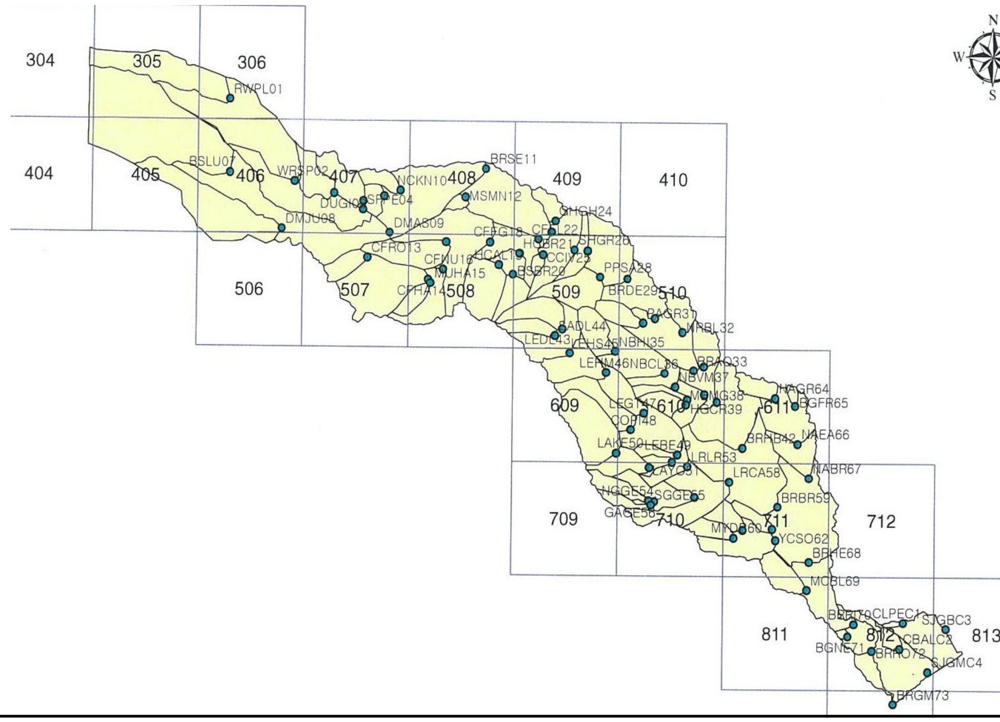
$$f''(x) = \frac{f(x+\Delta x) - 2f(x) + f(x-\Delta x)}{\Delta x^2}$$

## **Example 6.1 Derived from Brazos WAM Case Study** (Hydrology Manual Pages 138-169)

The Brazos WAM original hydrologic period-of-analysis of 1940-1997 is extended through 2012 for two of its 77 primary control points in Example 6.1 of the Hydrology Manual. The Brazos WAM and its hydrology extension are discussed in detail in the following two technical reports.

R.A. Wurbs, *Daily Water Availability Model for the Brazos River Basin and San Jacinto-Brazos Coastal Basin*, TWRI TR-513, 238 pages, May 2019.

R.A. Wurbs and G. Chun, *Hydrologic Period-of-Analysis Extension for the Brazos River Basin and San Jacinto-Brazos Coastal Basin Water Availability Model*, TCEQ, Contract 582-12-10220, 359 pages, October 2012.

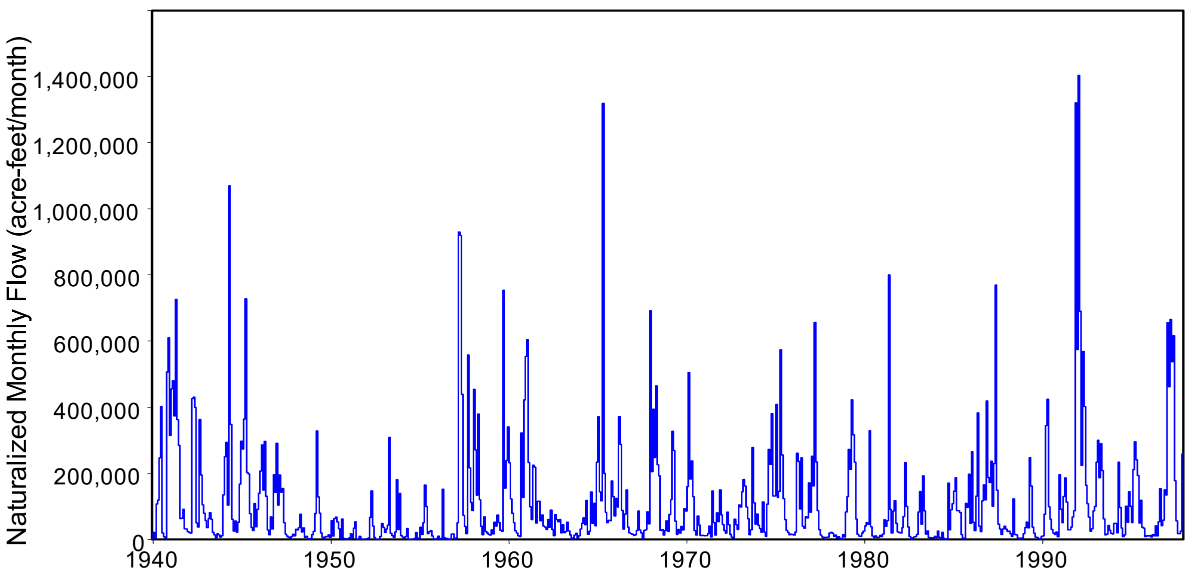



## Quadrangle Areas for the Cameron Gage on the Little River

(Table 6.4 on Page 139 of Hydrology Manual)

| Cameron Gage on Little River | | |
|---|---|---|
| Quadrangle Identifier | Watershed Area (sq miles) | Total Area Quadrangle (sq miles) |
| 710 | 1,896 | 4,092 |
| 610 | 1,470 | 4,050 |
| 609 | 2,129 | 4,050 |
| 711 | 77 | 4,092 |
| 709 | 324 | 4,092 |
| 509 | 1,063 | 4,009 |
| 508 | 115 | 4,009 |
| Total | 7,074 | 28,394 |

## 1940-1997 Naturalized Flow at Cameron Gage on Little River
(Figure 6.7 on Page 140)




## Low, Medium, High, and Flood Flows Used to Specify Flow Zones for the Model for Site of Cameron Gage on Little River
(Pages 110 and 141)

HU = 30% exceedance frequency known flow = 104,549 acre-feet/month

FL = 40% exceedance frequency known flow = 65,294 acre-feet/month

MU and HL = 60% exceedance frequency known flow = 28,988 ac-ft/month

LU and ML = 80% exceedance frequency known flow = 11,904 ac-ft/month

## Example 6.1 with Seven Quadrangles

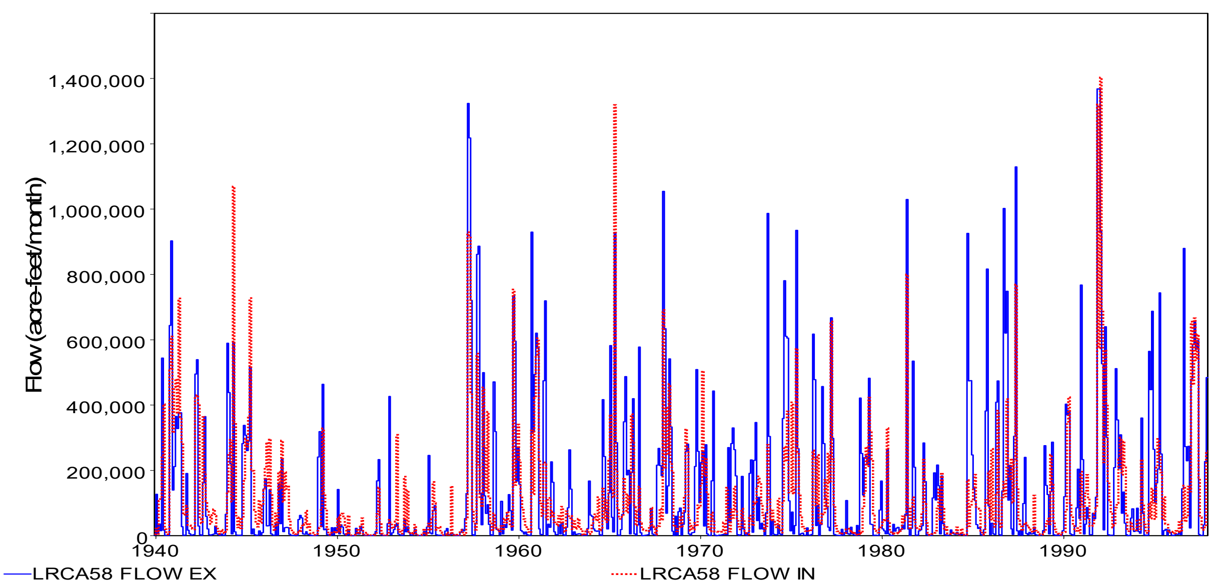
Number of Calibration Parameters = 4(13+5N) + 3

where N is the number of quadrangles

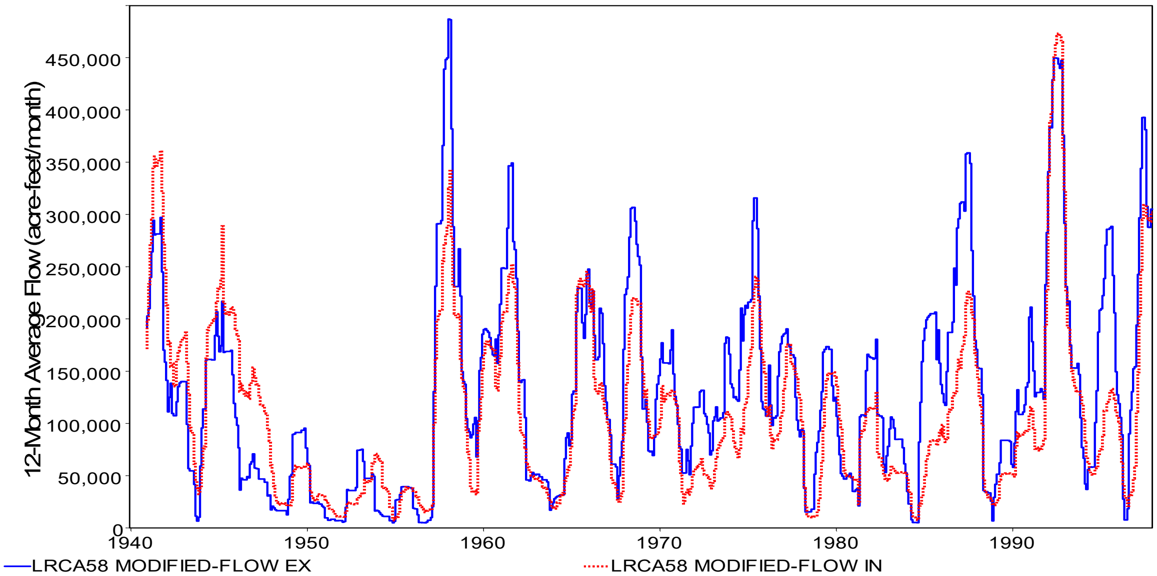
Number of Calibration Parameters = 4[13+5(7)] + 3

= 195

## Known and Computed Flows Based on Level 1 Calibration
(Figure 6.7 on Page 155)



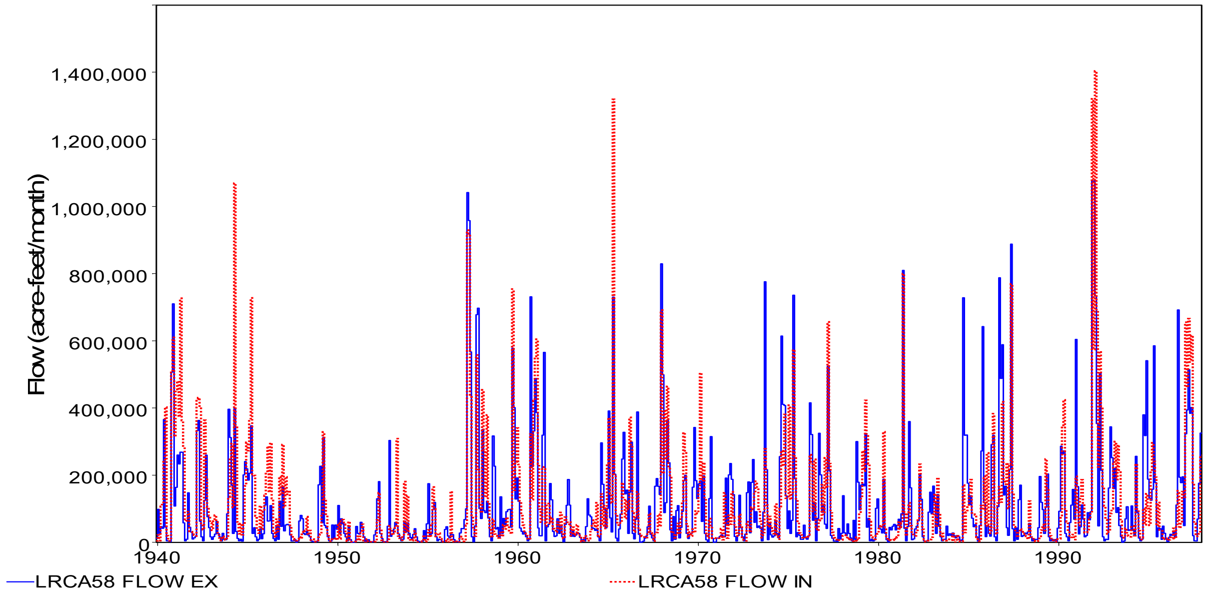
## **12-Month Moving Average of Flows with Level 1 Calibration**
(Figure 6.8 on Page 155)



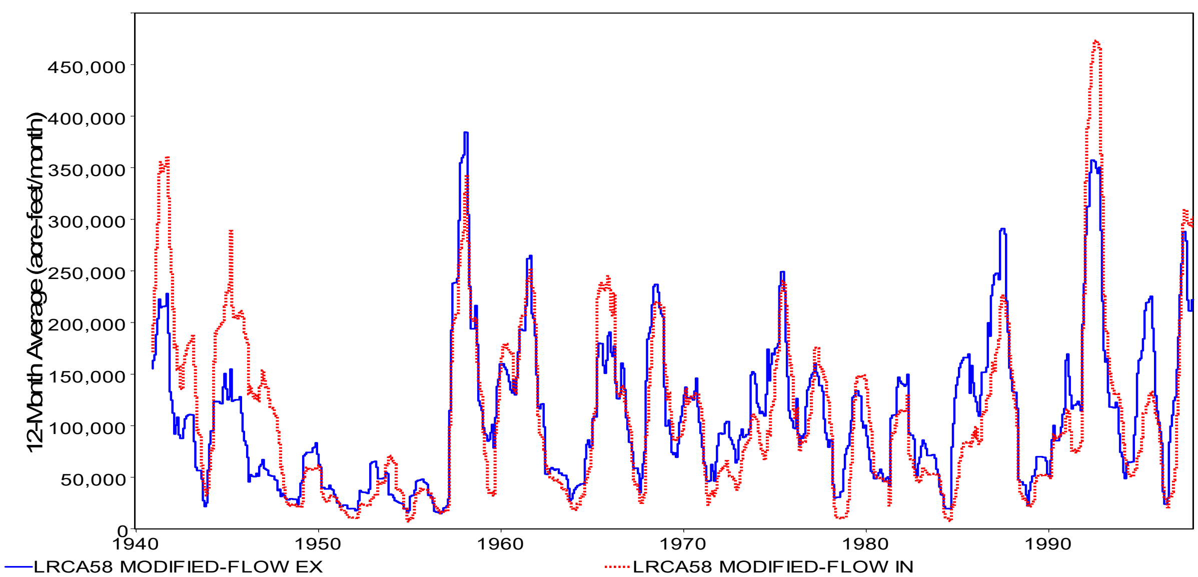

## **Level 2 Calibration Factors with FR and FX Records** (Table 6.16 Page 159)

| Exceedance Frequency | Known Flow (ac-ft/month) | Computed Flow (ac-ft/month) | Mean of Known Flows (ac-ft/month) | Mean of Computed Flows (ac-ft/month) | FX Record Factors |
|---|---|---|---|---|---|
| | | | 1,322.2 | 607.4 | 2.17672 |
| 95% | 2,706.4 | 900.2 | | | |
| | | | 4,082.8 | 1,083.4 | 3.76835 |
| 90% | 5,440.0 | 1126.6 | | | |
| | | | 8,646.7 | 1,377.2 | 6.27838 |
| 80% | 11,904 | 1,690.0 | | | |
| | | | 15,291 | 2,434.6 | 6.28063 |
| 70% | 19,041 | 3,309.6 | | | |
| | | | 23,741 | 4,746.2 | 5.00212 |
| 60% | 28,988 | 6,237.7 | | | |
| | | | 35,707 | 13,097 | 2.72622 |
| 50% | 44,799 | 18,830 | | | |
| | | | 54,133 | 25,712 | 2.10532 |
| 40% | 65,294 | 34,370 | | | |
| | | | 84,601 | 65,509 | 1.29145 |
| 30% | 104,549 | 109,140 | | | |
| | | | 132,425 | 17,0932 | 0.77472 |
| 20% | 165,070 | 233,080 | | | |
| | | | 223,354 | 31,3942 | 0.71145 |
| 10% | 290,433 | 459,524 | | | |
| | | | 357,701 | 53,1739 | 0.67270 |
| 5% | 426,869 | 617,683 | | | |
| | | | 690,688 | 87,8171 | 0.78651 |

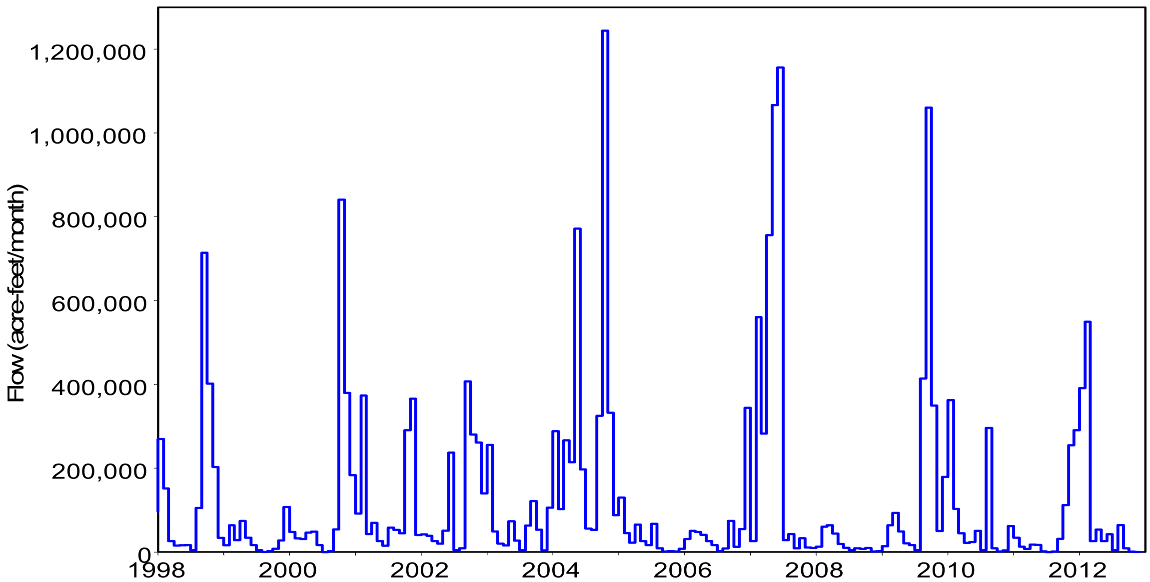
## 1940-1997 Known and Computed Flows after Final Calibration
(Figure 6.11 on Page 161)



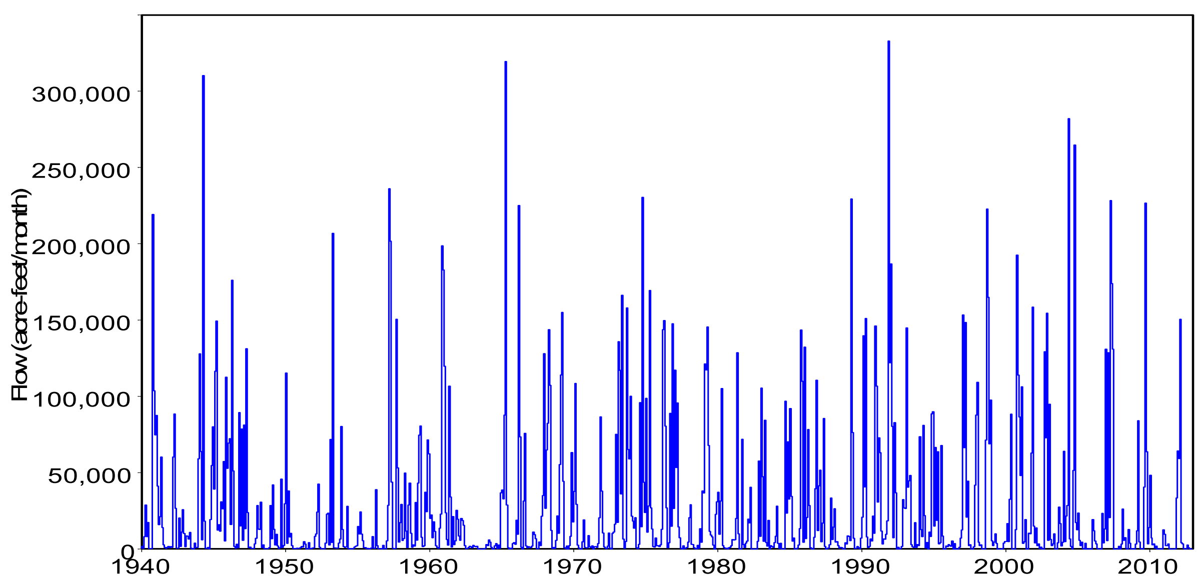

## 12-Month Moving Average of Flows After Final Calibration
(Figure 6.12 on Page 161)



**Extended 1998-2012 Naturalized Flows**
(Figure 6.20 on Page 168)




**Original 1940-1997 and Extended 1998-2012 Naturalized**
Flows (Figure 6.19 on Page 168)



## Flow Frequency Metrics in acre-feet/month (Table 6.11 Page 145)

| | Original | Level 1 | Final | | |
|---|---|---|---|---|---|
| | Known | Computed | Computed | Combined | Extension |
| | 1940-1997 | 1940-1997 | 1940-1997 | 1940-2012 | 1998-2012 |
| Mean | 26,882 | 27,615 | 26,770 | 27,103 | 27,957 |
| Std Dev | 46,900 | 51,031 | 46,988 | 48,572 | 54,691 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 95% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 90% | 125.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| 85% | 269.0 | 0.0 | 0.0 | 158.4 | 0.0 |
| 80% | 594.8 | 0.0 | 0.0 | 334.4 | 0.0 |
| 75% | 848.0 | 52.8 | 158.4 | 737.7 | 29.9 |
| 70% | 1,343 | 234.9 | 520.1 | 1,134 | 246.2 |
| 60% | 2,577 | 1,313 | 2,850 | 2,516 | 2,122 |
| 50% | 5,743 | 2,473 | 4,501 | 5,015 | 3,861 |
| 40% | 11,060 | 11,342 | 13,159 | 10,111 | 5,581 |
| 30% | 21,528 | 22,551 | 20,709 | 20,429 | 13,062 |
| 25% | 28,826 | 34,032 | 30,698 | 28,391 | 20,501 |
| 20% | 40,602 | 45,369 | 45,338 | 40,446 | 40,455 |
| 15% | 64,383 | 58,637 | 60,009 | 64,584 | 68,914 |
| 10% | 87,562 | 87,922 | 88,562 | 88,500 | 106,302 |
| 5% | 131,425 | 136,475 | 128,888 | 136,640 | 158,433 |
| 2% | 176,648 | 190,341 | 172,089 | 189,624 | 227,300 |
| 1% | 225,213 | 261,168 | 236,125 | 228,574 | 268,193 |
| 0.5% | 274,632 | 298,600 | 269,967 | 275,455 | 282,026 |
| Maximum | 332,958 | 387,373 | 350,228 | 332,958 | 282,026 |

## Summary Observations Regarding Hydrologic Regression Model for Extending Monthly Naturalized Stream Flows

- Both naturalized flows (IN records) and evaporation-precipitation depths (EV records) are extended using the same TWDB precipitation and evaporation databases which are updated annually.
- Calibration is complex. However, upon completion of calibration, the model can be applied for multiple updates without recalibration.
- This strategy can be applied to expeditiously extend the hydrology each year or each several years between more detailed extensions using conventional methods.
- The methodology is more accurate in replicating statistical metrics of stream flows than replicating individual flows in particular months. For typical WAM applications, statistical characteristics rather than naturalized stream flow in particular months are important.

## Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

## Module 1 – Simulation of Water Supply, Hydroelectric Energy, and Instream Flow Requirements

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Sponsored by the
Texas Commission on Environmental Quality

May 2021

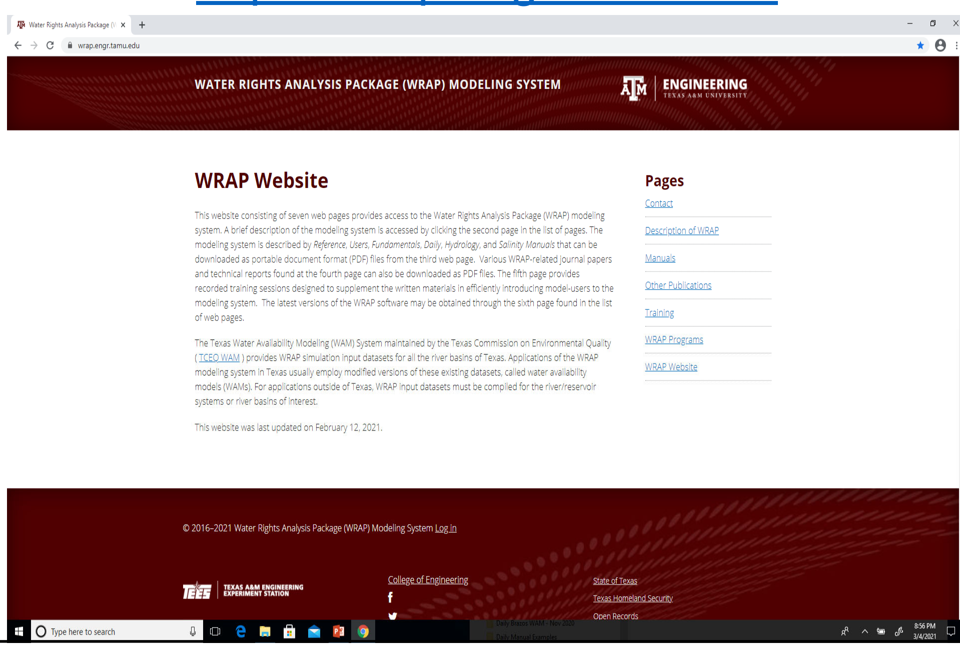
## Modules of Course on Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

1. Simulation of Water Supply, Hydroelectric Energy Generation, and Instream Flow Requirements
2. Setting Water Supply, Hydroelectric Energy, and Instream Flow Targets
3. River/Reservoir System Operations for Meeting the Targets
4. SIM Options for Simulating Reservoir Operations

## Water Rights Analysis Package (WRAP) Online Training Courses

1. Basics of Water Availability Modeling with the Water Rights Analysis Package
2. WRAP Program HYD Capabilities for Compiling, Analyzing, and Updating SIM Hydrology Input Datasets
3. **Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights**
4. Short-Term Conditional Reliability Modeling (CRM)
5. WRAP Daily Modeling System with Additional Features for Modeling Flood Control Reservoir Operations and Environmental Flow Standards

https://wrap.engr.tamu.edu/



## Components of the WRAP SIM or SIMD Simulation

***<u>Hydrologic Period-of-Analysis Natural Hydrology</u>***

Sequences of naturalized monthly flows and net evaporation-precipitation rates for the period-of-analysis at selected gaging stations are provided as input to the simulation model. Flows are distributed from gaged to ungaged sites within the simulation.

***Specified Scenario of Water Resources***
***<u>Development, Allocation, Management, and Use</u>***

A specified scenario of river/reservoir system water resources development, allocation, management, and use is simulated during an assumed repetition of historical natural hydrology.

***<u>Reliability, Frequency, and Other Water Availability Metrics</u>***

Measures of water supply reliability, stream flow and reservoir storage frequency, and other water availability information are developed.

## Water Rights in Simulation Models SIM and SIMD

Water resources development, management, allocation and use are modeled in SIM and SIMD as water rights associated with water right WR or instream flow IF records. SIMD flood control operations are based on also computationally treating operations associated with flood control reservoir FR and flood flow FF records as water rights.

- water use needs, demands, or targets
- on-stream and off-stream reservoirs, pumping plants, conveyance facilities, return flows, hydroelectric plants
- international treaties, interstate compacts, storage contracts
- requirements specified in water right permits
- reservoir system operating rules
- requirements for protection of instream flows

## WRAP Water Rights

- In WRAP terminology, a water right is a water right WR record or instream flow IF record and other auxiliary supporting input records for the SIM/SIMD simulation model.
- The approximately 6,200 water right permits in the Texas water rights permit system administered by the TCEQ are modeled in the 20 WAMs as over 10,000 WR records and over 800 IF records.
- The majority of the WR record water rights in the TCEQ WAMs are relatively simple sets of input records. However, the monthly SIM and daily SIMD versions of the simulation model provide flexible capabilities for modeling complex water management strategies and practices. Ingenuity and creativity are employed to model complex actual water management situations with "*model water rights*" comprised of an assortment of options controlled by any number of input records connected to the WR or IF records.

## Water Rights Priority Loop

(Portion of Reference Manual Figure 2.2 on Page 23)

Monthly loop repeated for each month of simulation.

Water Right Loop (repeated for each right in priority order)

1. The diversion, instream flow, or hydropower target is set.
2. The amount of water available to right is determined.
   Unappropriated flows are checked.
   Regulated flows are checked.
   (Channel losses are considered in checking flows.)
3. Diversions, reservoir releases, and return flows are made.
   (Includes reservoir water balance with iterative net evaporation-precipitation and hydropower computations.)
4. Available stream flow at all control points is adjusted.
   (Channel losses are considered in adjusting available flows.)
5. Water right output records are developed and written.

Control point and reservoir output records are developed and written.

## Simulation Priority Loop Computations for Each Water Right in a Given Month (SIM) or Day (SIMD)

1. **Target is set as discussed in Module 2 of this course.**
2. The amount of stream flow available is computed as briefly discussed in the present Module 1 of this course.
3. **Water is allocated to meet target as discussed in Modules 3 and 4 of this course.**
4. Available stream flow array is adjusted as briefly discussed in the present Module 1 of this course.
5. Results are recorded in the OUT and/or DSS output file as discussed in the present Module 1 of this course.

## CPFLOW Array Computations Maintaining Priorities

1. Target is set (Module 2).
2. Water availability is checked.

   The quantity of stream flow available to the water right is the minimum flow volume in the CPFLOW array at its control point and all downstream control points.
3. River/reservoir system operations (Modules 3 and 4).
4. Available stream flow array is adjusted.

   The CPFLOW array is adjusted at the control point of the water right and at all downstream control points.
5. Simulation results for this water right are recorded in output file.

## Stream Flow Quantities at Each Control Point

naturalized flow
regulated flow
unappropriated flow

## Stream Flow Quantities Associated with an Individual Water Right

available flow
streamflow depletion
return flow

## Water Right Priorities

- Available stream flow is allocated to each water right in turn in ranked priority order.
- Priority numbers establish a relative ranking for sequencing access to available stream flow for each water right in the simulation computations.
- The terms *"junior"* and *"senior"* refer to the relative priority of two or more water rights.

## Water Right Priority Numbers

- Priority numbers are entered in field 5 of the WR and IF records. (A permit priority date of May, 12, 1967 is entered as 19670512.)
- If two or more water rights have the same priority number on their WR or IF records, they are ranked in the relative order that their WR or IF records are entered in the DAT input file. The right read first from the DAT file is assigned the higher priority of the two or more water rights.
- The water use priority UP record provides options for changing priority numbers for selected groups of water rights.
- Optional schemes for modifying priorities are controlled by the priority circumvention PX record. The monthly stream flow availability factor AX record can be combined with a PX option.

## Alternative Water Right Priority Schemes Activated by NPOPT in JO Record Field 13

1. Automated natural upstream-to-downstream priority.
2. Priorities are set by sequencing of *WR* & *IF* records.
3. Priorities are set by sequencing of *CP* records.

## **Water Right WR Record** (Users Manual Pages 69-71)

CP – control point identifier
AMT – annual diversion or hydroelectric energy target
USE – use type identifier (or blank, LDAYS, NDAYS, XMONTH)
WRNUM(wr,7) – priority number
WRNUM(wr,5) – water right type
RFMETH – return flow specifications
RFAC – constant return flow factor
RFIDWR – identifier on RF record for monthly factors
RCP – control point to return flow with default of next downstream
FSCV – identifier of flow switch FS or cumulative volume CV record
DINDEX – drought index identifier
WRID, WRIDS1, WRID2 – two sets of water right and group identifiers

## **WR Record Water Right Types**
(Reference Manual Pages 86-89 and Users Manual Pages 69-71)

Type 1 – Access first to stream flow and then to reservoir storage. Reservoir storage refilling after meeting the diversion target.

Type 2 – Same as Type 1, except that no storage refilling is allowed.

Type 3 – Only releases from reservoir storage; no stream flow depletions and no refilling storage.

Type 4 – Inflow discharged to the river system.

Type 5 – Hydropower equivalent of Type 1.

Type 6 – Hydropower equivalent of Type 3.

Type 7 – Sets reservoir storage capacity (storage target).

Type 8 – Target computed for use with FS and TO records.

## Water Right Targets
## Representing Demands, Needs, or Authorized Amounts

WR Record Targets

diversion targets (water right types 1, 2, 3)
hydroelectric energy targets (types 5 and 6)
discharge targets (type 4)
storage targets (type 7)
TO/FS record targets (type 8)

IF Record Minimum Instream Flow Targets

## Instream Flow Targets (Minimum Regulated Flow Limits)

- Instream flow requirements are activated by IF records and are called IF record water rights.
- The IF record water right sets a target minimum regulated flow at a control point.
- Stream flow availability for junior WR record water rights are constrained by the minimum regulated flow targets set by senior IF record water rights.
- The same target setting options for WR records can be used for IF records. These options are discussed in Module 2
- Environmental standard ES, hydrologic condition HC, and pulse flow PF records are used with IF records to model SB3 environmental flow standard format.

## Instream Flow IF Record (Users Manual Pages 71-74)

CP – control point identifier
AMT – annual target for minimum instream flow limit
USE – use type identifier (or blank, LDAYS, NDAYS, XMONTH)
WRNUM(wr,7) – priority number
IFM(if,1) – inclusion/exclusion of reservoir releases for downstream use
IFM(if,2) – junior, largest, or smallest of two IF record targets at site
IFM(if,3) – reservoir release and second pass options
FSCV – identifier of flow switch FS or cumulative volume CV record
DINDEX – drought index identifier
WRID, WRIDS1, WRID2 – water right and group identifiers
CP2 – control point defining downstream end of reach

## Example 1 in Reference Manual Appendix C (Pages 387-393)

```
JD      3     2015       1       -1       -1
UC    mun     0.06    0.06    0.06    0.06    0.06    0.10
UC            0.12    0.12    0.11    0.10    0.09    0.06
UC    irr     0.00    0.00    0.00    0.00    0.20    0.30
UC            0.30    0.20    0.00    0.00    0.00    0.00
CP  CP-1    CP-2                         4            NONE
CP  CP-2    CP-4        0.083333         0                            0.10
CP  CP-3    CP-4                         0            CP-2            0.12
CP  CP-4    CP-5                         6            NONE            0.15
CP  CP-5     OUT                         0            NONE
**
WR  CP-1    1200     irr    1965             0.2                 WR-1
WR  CP-2                    9999                                 WR-2
WS Res A   80000
WR  CP-3   42000     irr    1975             0.1                 WR-3
WS Res B   30000
WR  CP-3                    8888                                 WR-4
WS Res B   40000
```

## Continuation of Example DAT File

```
WR  CP-4    26000      mun      1984    2         0.35                  2   WR-5
WS Res A    80000
WR  CP-5    18000      mun      1952    2                               2   WR-6
WS Res A    80000
IF  CP-5    12000                  0                 1     WR-7
**
SV Res A        0      825      2980     8640    22100    42700    73700    89600
SA              0      112       327      920     1760     2480     3750     4930
SV Res B        0      740      2680     7780    19800    38400    52900
SA              0      100       298      832     1580     2230     2690
**
DI      1      -1
IS      5       0    60000    108000   108001   120000
IP             50      100       100      120      120
DI      2       1    Res A
IS      4       0    20000     20001    81000
IP             80       80       100      100
ED
```

## Information Provided on WR or IF Record and Supporting WS, OR, UC, HP, SO, UP, RF, DI, ES, HC, EA, BU, ML, FS, MS, CV, PX, and TS Records

(Reference Manual Chapter 4 and Users Manual Chapter 3)

- Control point locations of all system components
- Annual demand volume in acre-feet/year
- Monthly demand distribution pattern
- Options for varying the monthly demand target as a function of reservoir storage, stream flow, or other variables
- Return flow specifications for WR record rights
- Reservoir storage capacity and operating rules
- Priority typically but not necessarily representing a date

## Time Series of Simulation Results

Simulation results variables are listed in the table on page 47 of the Users Manual and precisely defined in Chapter 5 of the Reference Manual. Simulation results are organized based on associations with control points, water rights, and/or reservoirs.

Reference Manual *Chapter 5 Organization of Simulation Results*

Users Manual *Chapter 3 SIM Input Records* (Pages 45-47)

OF Record Options for Data Storage System (DSS)
Input and Output Files

## Simulation Results Variables Associated with Control Points

1. naturalized stream flow (NAT)
2. regulated stream flow (REG)
3. unappropriated stream flow (UNA)
4. channel loss credits (CLC)
5. channel losses (CLO)
6. return flows returned here (RFR)
7. upstream reservoir releases (URR)
8. control point inflows (CPI)
9. end-of-month reservoir storage (STO)
10. reservoir net evaporation volume (EVA)
11. stream flow depletions (DEP)
12. diversion target (TAR)
13. diversion shortage (SHT)
14. diversion amount (DIV)
15. instream flow target (IFT)
16. instream flow shortage (IFS)

## Simulation Results Variables Associated with Water Rights

17. reservoir storage volume (STO)
18. reservoir net evaporation volume (EVA)
19. stream flow depletion (DEP)
20. diversion or hydropower target (TAR)
21. diversion or energy shortage (SHT)
22. diversion or energy amount (DIV)
23. available stream flow (ASF)
24. releases from secondary reservoirs (ROR)
25. return flow (RFL)
26. available increase (XAV)
27. instream flow IF record target (TIF)
28. combined instream flow IF right target (IFT)
29. instream flow IF right shortage (IFS)
30. instream flow IF right *FS* record flow (FSV)
31. instream flow IF right *FS* record count (FSC)

## Simulation Results Variables Associated with Reservoirs

32. end-of-month reservoir storage (STO)
33. net evaporation-precipitation volume (EVA)
34. power shortage or secondary energy (HPS)
35. hydroelectric energy generated (HPE)
36. inflows from stream flow depletions (RID)
37. inflows from reservoir releases (RIR)
38. releases accessible to hydropower (RAH)
39. releases not accessible to hydro (RNA)
40. adjusted evaporation-precipitation depth (EPD)
41. net evaporation depths (EVR)
42. reservoir water surface elevation (WSE)
43. reservoir storage capacity (RSC)

## Table 7.11 on Page 240 of Reference Manual

RELIABILITY SUMMARY FOR SELECTED WATER RIGHTS

| NAME | TARGET DIVERSION (AC-FT/YR) | MEAN SHORTAGE (AC-FT/YR) | *RELIABILITY* PERIOD (%) | *RELIABILITY* VOLUME (%) | PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100% | 95% | 90% | 75% | 50% | 25% | 1% | PERCENTAGE OF YEARS 100% | 98% | 95% | 90% | 75% | 50% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WR-6 | 60000.0 | 0.00 | 100.00 | 100.00 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| WR-1 | 9800.0 | 96.69 | 98.70 | 99.01 | 98.7 | 98.7 | 98.8 | 98.9 | 99.1 | 99.1 | 99.2 | 90.9 | 92.2 | 92.2 | 94.8 | 100.0 | 100.0 |
| WR-2 | 245000.0 | 9870.66 | 94.16 | 95.97 | 94.2 | 94.3 | 94.5 | 94.8 | 95.7 | 96.5 | 98.6 | 80.5 | 81.8 | 83.1 | 87.0 | 94.8 | 97.4 |
| WR-14 | 11300.0 | 158.46 | 98.92 | 98.60 | 98.9 | 98.9 | 98.9 | 99.0 | 99.0 | 99.1 | 99.4 | 90.9 | 90.9 | 92.2 | 96.1 | 98.7 | 98.7 |
| WR-20 | 34500.0 | 314.37 | 99.13 | 99.09 | 99.1 | 99.1 | 99.2 | 99.2 | 99.4 | 99.6 | 99.6 | 89.6 | 89.6 | 92.2 | 97.4 | 100.0 | 100.0 |
| WR-22 | 49600.0 | 1294.40 | 97.94 | 97.39 | 97.9 | 98.2 | 98.4 | 98.6 | 99.0 | 99.0 | 99.2 | 80.5 | 83.1 | 87.0 | 92.2 | 96.1 | 100.0 |
| WR-16 | 32300.0 | 2380.99 | 95.56 | 92.63 | 95.6 | 95.9 | 96.1 | 96.3 | 96.8 | 96.9 | 97.2 | 62.3 | 68.8 | 70.1 | 77.9 | 81.8 | 97.4 |
| WR-17 | 44800.0 | 4671.20 | 94.70 | 89.57 | 94.7 | 94.8 | 95.0 | 95.5 | 96.0 | 96.5 | 96.8 | 55.8 | 58.4 | 59.7 | 67.5 | 75.3 | 94.8 |
| WR-13 | 18200.0 | 831.32 | 96.00 | 95.43 | 96.0 | 96.0 | 96.0 | 96.3 | 96.6 | 96.9 | 96.9 | 72.7 | 72.7 | 74.0 | 76.6 | 93.5 | 100.0 |
| WR-19 | 39000.0 | 2050.68 | 95.78 | 94.74 | 95.8 | 95.8 | 95.8 | 95.9 | 96.2 | 96.4 | 96.6 | 67.5 | 67.5 | 67.5 | 72.7 | 92.2 | 100.0 |
| WR-21 | 95600.0 | 6245.38 | 94.59 | 93.47 | 94.6 | 94.8 | 94.9 | 95.0 | 95.2 | 95.3 | 96.0 | 61.0 | 62.3 | 62.3 | 64.9 | 90.9 | 100.0 |
| WR-8 | 82760.0 | 4120.81 | 93.94 | 95.02 | 93.9 | 93.9 | 94.4 | 94.6 | 94.8 | 95.5 | 97.0 | 83.1 | 83.1 | 85.7 | 87.0 | 92.2 | 97.4 |
| WR-9 | 97500.0 | 6508.18 | 92.32 | 93.32 | 92.3 | 92.5 | 92.5 | 92.7 | 93.3 | 93.4 | 93.8 | 79.2 | 80.5 | 81.8 | 84.4 | 90.9 | 93.5 |
| WR-10 | 25610.0 | 4251.55 | 79.00 | 83.40 | 79.0 | 79.4 | 79.5 | 81.2 | 83.1 | 85.4 | 94.3 | 53.2 | 54.5 | 57.1 | 63.6 | 74.0 | 84.4 |
| WR-11 | 42000.0 | 3561.08 | 87.88 | 91.52 | 87.9 | 88.1 | 88.5 | 89.3 | 91.6 | 94.0 | 97.2 | 63.6 | 64.9 | 68.8 | 77.9 | 89.6 | 93.5 |
| WR-3 | 18000.0 | 998.79 | 94.48 | 94.45 | 94.5 | 94.5 | 94.6 | 94.6 | 94.6 | 94.9 | 95.1 | 83.1 | 83.1 | 83.1 | 84.4 | 89.6 | 96.1 |
| WR-12 | 92100.0 | 31627.97 | 80.52 | 65.66 | 80.5 | 81.2 | 81.6 | 82.7 | 85.7 | 89.8 | 93.5 | 14.3 | 15.6 | 19.5 | 20.8 | 35.1 | 72.7 |
| WR-18 | 25400.0 | 3309.79 | 89.07 | 86.97 | 89.1 | 89.1 | 89.1 | 89.2 | 89.5 | 89.8 | 90.2 | 37.7 | 37.7 | 40.3 | 41.6 | 81.8 | 98.7 |
| WR-7 | 20800.0 | 0.00 | 100.00 | 100.00 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| WR-15 | 88000.0 | 4209.25 | 94.91 | 95.22 | 94.9 | 94.9 | 95.1 | 95.2 | 95.5 | 95.9 | 96.3 | 87.0 | 87.0 | 87.0 | 88.3 | 92.2 | 93.5 |
| WR-23 | 74500.0 | 23506.57 | 85.39 | 68.45 | 85.4 | 85.4 | 85.4 | 85.8 | 87.0 | 87.9 | 89.0 | 26.0 | 28.6 | 28.6 | 35.1 | 42.9 | 63.6 |
| WR-24 | 900000.1 | 29923.05 | 95.56 | 96.68 | 95.6 | 95.7 | 95.8 | 95.9 | 96.5 | 97.8 | 98.9 | 81.8 | 83.1 | 84.4 | 90.9 | 94.8 | 98.7 |
| Total | 2106770.0 | 139931.17 | | 93.36 | | | | | | | | | | | | | |

## Table 7.12 on Page 240 of Reference Manual

RELIABILITY SUMMARY FOR SELECTED HYDROELECTRIC POWER PROJECTS

| NAME | ENERGY TARGET | MEAN SHORTAGE | *RELIABILITY* PERIOD (%) | *RELIABILITY* AMOUNT (%) | PERCENTAGE OF MONTHS WITH ENERGY GENERATION EQUALING OR EXCEEDING PERCENTAGE OF TARGET 100% | 95% | 90% | 75% | 50% | 25% | 1% | PERCENTAGE OF YEARS 100% | 98% | 95% | 90% | 75% | 50% | 1% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Whit | 36000.0 | 1853.81 | 91.88 | 94.85 | 91.9 | 92.1 | 92.2 | 92.7 | 95.1 | 96.1 | 99.4 | 74.0 | 74.0 | 76.6 | 83.1 | 93.5 | 97.4 | 100.0 |
| Total | 36000.0 | 1853.81 | | 94.85 | | | | | | | | | | | | | | |

## Firm and Safe Yield for Water Supply or Hydropower

Firm yield is the maximum annual diversion target that can be maintained throughout the simulation with no shortages. The firm yield is the estimated maximum diversion with volume and period reliabilities of 100% based on the SIM simulation with all of its premises and approximations.

The term *safe yield* is adopted in WRAP to refer to a variation of firm yield that incorporates a storage reserve rather than completely emptying the reservoir or multiple-reservoir system.

## SIM Automated Search for Firm or Safe Yield Controlled by the FY Record

Alternative strategies for computing firm or safe yield:

- Multiple trial-and-error SIM simulations with the diversion target manually changed for each execution of SIM.
- Automatic repetition of the simulation computations within a single execution of SIM as specified by the FY record.

## SIM Firm Yield FY Record Parameters

(Fundamentals Manual page 78, Users Manual Pages 55-57)

FYIN(1) – Fraction of monthly target that must be met.
FYIN(2) – Initial value for the annual diversion target.
FYIN(3) – Incremental decrease for first level of decreases.
FYIN(4) – Incremental decrease for second level of decreases.
FYIN(5) – Incremental decrease for third level of decreases.
FYWRID – Water right identifier.
FYGROUP – Water right group identifier.
MFY – Proportional to amounts in WR record field 3.
FYC(1) – Options for applying FYIN(1).
FYC(2) – Reservoir storage reserve options.
FYC(3) – Number of months of water supply storage reserve.
FYIN(6) – Required storage reservoir plus inactive storage.

## Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

### Four Course Modules

1. Simulation of Water Supply, Hydroelectric Energy Generation, and Instream Flow Requirements
2. Setting Water Supply, Hydroelectric Energy, and Instream Flow Targets
3. River/Reservoir System Operations for Meeting the Targets
4. SIM Options for Simulating Reservoir Operations

## Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

## Module 2 – Setting Water Supply, Hydroelectric Energy, and Instream Flow Targets

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Zachry Department of Civil and Environmental Engineering
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Sponsored by the
Texas Commission on Environmental Quality

May 2021

## Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

### Course Modules

1. Simulation of Water Supply, Hydroelectric Energy Generation, and Instream Flow Requirements
2. Setting Water Supply, Hydroelectric Energy, and Instream Flow Targets
3. River/Reservoir System Operations for Meeting the Targets
4. SIM Options for Simulating Reservoir Operations

## Simulation Priority Loop Computations for Each Water Right in a Given Month (SIM) or Day (SIMD)

1. The water right target is set as discussed in the present Module 2 of this course.
2. The availability of stream flow for the water right is determined as discussed in the preceding Module 1.
3. River/reservoir system operations allocate water to meet the target as discussed in Modules 3 and 4 of this course.
4. The available stream flow array is adjusted for the effects of the water right as discussed in Module 1.
5. Results are recorded as discussed in Module 1.

## Definition of WRAP "*Model Water Right*"

In WRAP terminology, a water right is a water right WR record or instream flow IF record and other auxiliary supporting input records for the SIM simulation model.

## Options for Setting **WR** and **IF** Record Targets (Module 2)

- Constant annual volume and monthly distribution (water use coefficient *UC* records)
- Drought index to vary target with reservoir storage (drought index *DI*, index storage *IS*, and percentage *IP* records)
- Targets as a function of stream flow (target options *TO*, flow switch *FS*, cumulative volume *CV* records)
- Environmental flow standards (environmental standard *ES*, hydrologic condition *HC*, and pulse flow *PF* records)
- Predetermined targets (target series *TS* records)

## Sequencing of Target Building Options

Pages 122-124 of Reference Manual section entitled *Setting Diversion, Instream Flow, and Hydropower Targets.*

Pages 87-88 of Users Manual section entitled *Framework for Building Diversion, Instream Flow, and Hydropower Targets.*

## Sequencing of Target Building Options

1. WR/IF annual amount and UC record monthly coefficients
2. Backup right BU record (step 2 or 10)
3. DI/IS/IP record drought index (step 3 or 6)
4. Certain target options TO record options
5. TS record time series
6. DI/IS/IP record drought index (step 3 or 6)
7. Certain target options TO record options
8. FS or CV record options
9. Other FS or CV record options
10. Backup right BU record (step 2 or 10)
11. SO record limit on withdrawals from storage
12. SO record WR diversion or IF flow limit

## Options Associated with River/Reservoir Operational Strategies and Practices for Supplying the Targets (Modules 3 and 4)

- Storage, diversions, and releases from reservoir storage (water right storage *WS* record)
- Return flows from water supply diversions (*WR* record)
- Hydroelectric power operations (*HP* record)
- Monthly, seasonal, or annual limits on diversions, stream flow depletions or withdrawals from storage (supplemental options *SO* record)
- Stream flow depletions from alternate locations (supplemental options *SO* record)
- Secondary backup right that supplies shortages incurred by other rights (backup *BU* record)

## **Water Right WR Record** (Users Manual Pages 69-71)

CP – control point identifier

**AMT – annual diversion** (acre-feet/year) **or hydroelectric energy** (megawatt-hours/year) **target**

**USE – use type identifier (or blank, LDAYS, NDAYS, XMONTH)**

WRNUM(wr,7) – priority number

**WRNUM(wr,5) – water right type**

RFMETH – return flow specifications

RFAC – constant return flow factor

RFIDWR – identifier on RF record for monthly factors

RCP – control point to return flow with default of next downstream

**FSCV – identifier of flow switch FS or cumulative volume CV record**

**DINDEX – drought index identifier**

WRID, WRIDS1, WRID2 – water right and group identifiers

## **WR Record Water Right Types**

(Reference Manual Pages 86-89 and Users Manual Pages 69-71)

Type 1 – Access first to stream flow and then to reservoir storage. Reservoir storage refilling after meeting the diversion target.

Type 2 – Same as Type 1, except that no storage refilling is allowed.

Type 3 – Only releases from reservoir storage; no stream flow depletions and no refilling storage.

Type 4 – Inflow discharged to the river system.

Type 5 – Hydropower equivalent of Type 1.

Type 6 – Hydropower equivalent of Type 3.

Type 7 – Sets reservoir storage capacity (storage target).

Type 8 – Target computed for use with FS and TO records.

## Water Right Targets Representing Water Demands, Needs, Requirements, or Authorized Amounts

WR Record Targets

diversion targets (water right types 1, 2, 3)
hydroelectric energy targets (types 5 and 6)
discharge targets (type 4)
storage targets (type 7)
TO/FS record targets (type 8)

IF Record Minimum Instream Flow Targets

## Hydroelectric Energy Generation
(Reference Manual Pages 96-101)

- WR record type 5 and type 6 water rights generate hydroelectric energy. Monthly hydroelectric energy generation targets in megawatt-hours are set similarly to monthly water supply diversion targets in acre-feet.
- A hydropower HP record for a WR record water right provides input regarding hydraulic-to-electric efficiency, tailwater elevation, turbine invert elevation and discharge capacity, and a maximum limit on secondary energy generation.

## Instream Flow Requirements
(Reference Manual Pages 101-118, 121-135)

- Instream flow requirements are activated by IF records and are called IF record water rights.
- The IF record water right sets a target minimum regulated flow at a control point.
- Stream flow availability for junior WR record water rights are constrained by the minimum regulated flow targets set by senior IF record water rights.
- The same target setting options for WR records can be used for IF records. These options are discussed in Module 2
- Environmental standard ES, hydrologic condition HC, and pulse flow PF records are used with IF records to model SB3 environmental flow standard format.

## Instream Flow IF Record (Users Manual Pages 71-74)

CP – control point identifier

**AMT – annual target for minimum instream flow target in ac-ft/year**

**USE – use type identifier (or blank, LDAYS, NDAYS, XMONTH)**

WRNUM(wr,7) – priority number

IFM(if,1) – inclusion/exclusion of reservoir releases for downstream use

IFM(if,2) – junior, largest, or smallest of two IF record targets at site

IFM(if,3) – reservoir release and second pass options

**FSCV – identifier of flow switch FS or cumulative volume CV record**

**DINDEX – drought index identifier**

WRID, WRIDS1, WRID2 – water right and group identifiers

CP2 – control point defining downstream end of reach

## Multiple IF Record Rights at the Same Control Point

- Multiple IF rights can be located at the same control point.
- Each IF record may specify a different regulated flow target at a different priority.
- The default for IF record parameter IFM(if,2) is for the most junior IF record to replace the preceding IF record targets.
- IFM(if,2) options 2 and 3 adopt the largest or smallest target for that IF record water right considered at that control point in the water rights priority sequence.

## Other IF Record IFM Options

Instream flow targets can be met with the total regulated flow at the control point or reservoir releases for other water rights can be excluded as specified by IFM(if,1) in IF record field 6.

Like WR record rights, IF record rights can call for upstream reservoir releases to meet their targets. IFM(if,3) options 3 and 4 in IF record field 8 specifies that releases are made from the one or more reservoirs identified on the WS records that follow the IF record.

An optional second pass through the water rights priority sequence is activated by IFM(if,3) options 2 an 4.

## Option for a Second Pass through Water Rights Priority Sequence Simulation

- The second pass option is activated by either PASS2 in JO record field 14 or IFM(if,3) in IF record field 8.
- The only purpose for the second pass option is to credit contributions of junior rights in meeting senior IF record instream flow targets in regard to the following: (1) return flows, (2) hydropower releases, and (3) reservoir releases for downstream diversions. Return flow and hydropower issues are alternatively handled with next-month options.
- The Reference and Users Manuals recommend that the second pass option be used only if definitely needed and then used with caution.

## Alternative Strategies for Modeling IF Record Instream Flow Requirements

1. IF record instream flow targets can be set similarly to WR record diversion and hydropower power targets. This strategy employs IF and UC records optionally combined with TO, FS, CV, and/or other SIM input records that are also applicable to WR record water rights.
2. A recently added alternative approach for setting IF record instream flow targets is designed in the form of SB3 environmental flow standards. This strategy employs IF, ES, HC, and PF records.

## EFS for Gage on Little River at Cameron
(Table 8.1 on Page 195 of Daily Manual)

| Season | Subsistence Flow | Hydrologic Condition | Base Flow | Dry Condition Seasonal Pulse | Average Cond. Seasonal Pulse | Wet Condition Seasonal Pulse |
|---|---|---|---|---|---|---|
| | 32 cfs | Dry | 110 cfs | 1 per season | 3 per season | 2 per season |
| Winter | -0- | Average | 190 cfs | Trigger 1,080 cfs | Trigger 1,080 cfs | Trigger 2,140 cfs |
| | -0- | Wet | 460 cfs | Volume 6,680 af | Volume 6,680 af | Volume 14,900 af |
| | | | | Duration 8 days | Duration 8 days | Duration 10 days |
| | 32 cfs | Dry | 140 cfs | 1 per season | 3 per season | 2 per season |
| Spring | -0- | Average | 310 cfs | Trigger 3,200 cfs | Trigger 3,200 cfs | Trigger 4,790 cfs |
| | -0- | Wet | 760 cfs | Volume 23,900 af | Volume 23,900 af | Volume 38,400 af |
| | | | | Duration 12 days | Duration 12 days | Duration 14 days |
| | 32 cfs | Dry | 97 cfs | 1 per season | 3 per season | 2 per season |
| Summer | -0- | Average | 160 cfs | Trigger 560 cfs | Trigger 560 cfs | Trigger 990 cfs |
| | -0- | Wet | 330 cfs | Volume 2,860 af | Volume 2,860 af | Volume 5,550 af |
| | | | | Duration 6 days | Duration 6 days | Duration 8 days |

## SB3 Environmental Flow Standards

Reference Manual, Chapter 4 Water Management in the Simulation Model, Environmental Instream Flow Standards (pages 111-118).

Daily Manual, Chapter 6 Environmental Flow Standards.
Daily Manual, Chapter 8 Environmental Flow Standard Examples.

Online Course: WRAP Daily Modeling System
Module 5 SB3 Environmental Flow Standards

## SIM and SIMD Input Records for Modeling Instream Flow Requirements

Users Manual Chapter 3 SIM (Pages 71-79)

IF Record – Instream Flow Right
**ES Record – Environmental Flow Standards**
**HC Record – Hydrologic Conditions**
**HI Record – Hydrologic Index**

Users Manual Chapter 4 SIMD (Pages 153-159)

**PF Record – High Pulse Flow Component of EFS**
**PO Record – Pulse Flow Supplement Options**

Users Manual Chapter 3 SIM

UC, WS, DI/IP/IS, SO, and TO records may be used with either IF or WR record water rights.

## ES Record – Environmental Flow Standards

(Users Manual Pages 74-76)

CD – Record identifier ES

ESF – Flow Regime Components

- SUBS Subsistence flow
- SF50 Subsistence flow with 50% rule
- BASE Base flow
- HAnn High flow. Maximum of nn periods/year
- HSnn HSnn. Maximum of nn periods/season
- PFES PF record pulse flows only

ESHC – Hydrologic condition defined by HC record

ESQ – 12 Mean monthly flow rate limits in cfs for Jan-Dec

ESQX – ESQ multiplier factor

## Options for Setting WR and IF Record Targets

- Constant annual volume and monthly distribution (water use coefficient *UC* records)
- Environmental flow standards (environmental standard *ES*, hydrologic condition *HC*, and pulse flow *PF* records)
- Predetermined targets (target series *TS* records)
- Drought index to vary target with reservoir storage (drought index *DI*, index storage *IS*, and percentage *IP* records)
- Targets as a function of stream flow (target options *TO*, flow switch *FS,* cumulative volume *CV* records)

## Drought or Storage Index

(Reference Manual Pages 126-128; Users Manual Pages 115-116)

DI Record – Drought Index Reservoirs

IS Record – Drought Index Storage

IP Record – Drought Index Percentages

IM Record – Monthly Switches

## Example Drought Indices

(Reference Manual Page 128)

```
DI     1       3  Belton  George   Grang
IS     4     0.0 224080. 224080. 1466320
IP           0.0     0.0   100.0   100.0
IM     1   2   3   4   5  -5  -5  -5  -5  -5  11  12
**  positive = apply, negative = repeat, 0 = not apply
**
DI     2       3      PK    Whit   WacoL
IS     4     0.0 555776. 555776. 3391940
IP           0.0     0.0   100.0   100.0
```

## Target Options TO Record

### Modification of Targets as Function of Stream Flow, Storage, or Other Water Rights

(Reference Manual Pages 124-125; Users Manual Pages 94-96)

TOTARGET – options for basing target on flow, storage, or other water rights

FACT – multiplier factor

TOCOMB – combining operations

TOLIM(1) and TOLIM(2) – lower and upper limits on target

TOFLOW, TORES, TOWR – control point, reservoir, and water right identifiers

## TO Record Example on Reference Manual Pages 124-125

**The instream flow target at CP1 is computed as 25% of the summation of available flow at CP2 and CP3, except the IF target can not exceed the naturalized flow at CP1 and must fall with the range of 100 to 500 acre-feet/month.**

```
IF    CP1                         1985
TO      3     0.25                                        CP2
TO      3     0.25      ADD                               CP3
TO      1      CP1      MIN     100.     500.
```

## Example 5 on Pages 416-419 of Reference Manual Appendix C

```
JD      2    2006        1        1        1
CP    CP1      CP3                                    NONE
CP    CP2      CP3                                    NONE
CP    CP3      CP4                                    NONE
CP    CP4      CP5                                    NONE
CP    CP5      OUT                                    NONE
**
**  Water Right IF1  ---------------------------------------------
IF    CP4                 1900       2                      IF1
TO      1                                  CP4
TO      1    - 1.0    ADD                  CP1
TO      1    - 1.0    ADD      3.0     68.0      CP2
**  Water Right WR1  ---------------------------------------------
WR    CP1    2400.          1985                                 WR1
WS Res 1    5000.      .1       1.
**  Water Right WR2  ---------------------------------------------
WR    CP2    2400.          1978                                 WR2
WS Res 2    5000.      .1       1.
```

```
**   Water Right WR3  --------------------------------------------
WR   CP5   4800.          1903                                  WR3
TO     1             MIN                  CP5
**   Water Right WR4  --------------------------------------------
WR   CP4   3600.          1950                                  WR4
WS Res 3   8000.       .1     1.
**   Water Right WR5  --------------------------------------------
WR   CP4      0.          2000   3        1.0      CP1          WR5
WS Res 3   8000.       .1     1.
TO     5                                Res 1
TO     2             MIN                  CP1
**   Water Right WR6  --------------------------------------------
WR   CP4      0.          2000   3        1.0      CP2          WR6
WS Res 3   8000.       .1     1.
TO     5                                        Res 2
**   Water Right WR7  --------------------------------------------
WR   CP1      0.          2001                                  WR7
WS Res 1   5000.       .1     1.
**   Water Right WR8  --------------------------------------------
WR   CP2      0.          2001                                  WR8
WS Res 2   5000.       .1     1.
ED
```

## Flow Switch FS Record

(Reference Manual Pages 128-136; Users Manual Pages 102-105)

FSV – cumulative flow variable defining switch
FSCP – control point of switch variable location
FSX(FS,1) – factors applied if flow is within bounds
FSX(FS,2) – factors applied if flow is not within bounds
FSI(FS,2) – options for applying the flow volume bounds
FSI(FS,3) – lower bound on number of periods
FSI(FS,4) – upper bound on number of periods
FSI(FS,5), FSI(FS,6), FSI(FS,7), FSI(FS,8) – parameters defining flow summation period
FSI(FS,9) – record flow switch results in MSS file
FSWR(FS) – water right identifier for relevant FSV options
FSI(FS,14) – month for setting FSV volume and count to zero

## Example 8 on Reference Manual Pages 432-434 Illustrating Flow Switch FS Record Capabilities

The monthly diversion target is 333.33 acre-feet if the 12-month cumulated regulated flow volume at CP-2 falls within the following range.

3,000 ac-ft ≤ 12-month cumulative regulated flow volume ≤ 9,000 ac-ft

Otherwise, the diversion target is 1,000 acre-feet.

```
JD     4    2013       1       -1       -1
JO     3
CP   CP-1    CP-2                                    NONE
CP   CP-2     OUT                                    NONE
**
WR   CP-1   12000                                    Flow Switch
FS      1    CP-2 0.33333     1.0    3000.    9000.    1    0    0   11
ED
```

## Cumulative Volume CV Record

(Reference Manual Pages 128-136; Users Manual Pages 100-102)

CVV – cumulative flow variable
CVCP – control point of CVV variable location
FSX(1) – factor by which CVV is multiplied (default = 1.0)
FSX(2) – factor added to CVV (default = 0.0)
FSX(3) – lower bound (default = 0.0)
FSX(4) – upper bound (default = 9,000,000,000.0
FSI(2) – options for applying bounds
FSI(3) – options for combining with preceding target
FSI(FS,5), FSI(FS,6), FSI(FS,7), FSI(FS,8) – parameters defining flow summation period
FSI(FS,9) – record flow switch results in MSS file
FSWR(FS) – water right identifier for relevant FSV options
FSI(FS,14) – month for setting FSV volume and count to zero

## Simulation Priority Loop Computations for Each Water Right in a Given Month (SIM) or Day (SIMD)

1. The water right target is set as discussed in the present Module 2 of this course.
2. The availability of stream flow for the water right is checked as discussed in the preceding Module 1.
3. River/reservoir system operations allocate water to meet the target as discussed in Modules 3 and 4 of this course.
4. The available stream flow array is adjusted for the effects of the water right as discussed in Module 1.
5. Results are recorded in output file as discussed in Module 1.

## Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

### Course Modules

1. Simulation of Water Supply, Hydroelectric Energy Generation, and Instream Flow Requirements
2. Setting Water Supply, Hydroelectric Energy, and Instream Flow Targets (this module)
3. River/Reservoir System Operations for Meeting the Targets (the next module)
4. SIM Options for Simulating Reservoir Operations

## Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

## Module 3 – River/Reservoir System Operations for Meeting the Targets

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Sponsored by the
Texas Commission on Environmental Quality

May 2021

## Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

## Course Modules

1. Simulation of Water Supply, Hydroelectric Energy Generation, and Instream Flow Requirements
2. Setting Water Supply, Hydroelectric Energy, and Instream Flow Targets
3. River/Reservoir System Operations for Meeting the Targets
4. SIM Options for Simulating Reservoir Operations

## Simulation Computations for Each Water Right in Priority Sequence

1. The water supply, hydropower, or instream flow target is computed as discussed in the preceding Module 2.
2. The quantity of stream flow available for supplying the target is determined from the CPFLOW array.
3. The target is supplied subject to availability of stream flow and reservoir storage by the river/reservoir operations discussed in Modules 3 and 4.
4. The CPFLOW available stream flow array is adjusted.
5. Results are recorded in the OUT and/or DSS output files.

## River/Reservoir System Operations

- Operating rules defined by water right types
- Water supply return flows and conveyance
- Instream flow requirements
- Hydroelectric power operations
- Run-of-river diversions
- Reservoir storage
- Primary and secondary reservoirs
- Multiple reservoir system operations
- Off-channel storage
- Multiple-owner reservoirs
- Backup rights
- Dual simulation option

## Iterative Water Accounting Algorithms

Computation of Net Evaporation-Precipitation (EP) Volumes

EP volume = (average reservoir surface area) x EP depth

Average reservoir surface area in acres is a function of beginning-of-month and end-of-month storage volumes. End-of-month storage volume is a function of EP volume.

Hydroelectric Energy Generation

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

Energy E (megawatt-hours), discharge Q (acre-feet/month), head H (feet), efficiency (dimensionless), time t (month), unit weight γ (62.4 $lb/ft^3$), and conversion factors (0.0010237).
H depends upon Q which depends upon H.
[Reference Manual page 99]

## Information for Setting and Meeting Targets

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

## **Water Right WR Record** (Users Manual Pages 69-71)

CP – control point identifier
AMT – annual diversion or hydroelectric energy target
USE – use type identifier (or blank, LDAYS, NDAYS, XMONTH)
WRNUM(wr,7) – priority number
WRNUM(wr,5) – water right type (Default is type 1.)
RFMETH – return flow specifications
RFAC – constant return flow factor
RFIDWR – identifier on RF record for monthly factors
RCP – control point to return flow with default of next downstream
FSCV – identifier of flow switch FS or cumulative volume CV record
DINDEX – drought index identifier
WRID, WRIDS1, WRID2 – water right and group identifiers

## **WR Record Water Right Types**
(Reference Manual Pages 86-89 and Users Manual Pages 69-71)

Type 1 – Access first to stream flow and then to reservoir storage. Reservoir storage refilling after meeting the diversion target.

Type 2 – Same as Type 1, except that no storage refilling is allowed.

Type 3 – Only releases from reservoir storage; no stream flow depletions and no refilling storage.

Type 4 – Inflow discharged to the river system.

Type 5 – Hydropower equivalent of Type 1.

Type 6 – Hydropower equivalent of Type 3.

Type 7 – Sets reservoir storage capacity (storage target).

Type 8 – Target computed for use with FS and TO records.

## Water Right Targets Representing Demands, Needs, Requirements, or Authorized Amounts (Module 2)

WR record diversion targets (water right types 1, 2, 3), hydroelectric energy targets (types 5 and 6), discharge targets (type 4), storage targets (type 7), or TO/FS record targets (type 8).

IF record minimum instream flow targets.

## Options for Setting WR and IF Record Targets Covered in Module 2

- Constant annual volume and monthly distribution (water use coefficient *UC* records)
- Environmental flow standards (environmental standard *ES*, hydrologic condition *HC*, and pulse flow *PF* records)
- Predetermined targets (target series *TS* records)
- Drought index to vary target with reservoir storage (drought index *DI*, index storage *IS*, and percentage *IP* records)
- Targets as a function of stream flow (target options *TO*, flow switch *FS,* cumulative volume *CV* records)

## Capabilities for Simulating River/Reservoir System Operational Strategies and Practices Covered in Module 3

- Diversion return flows and conveyance facilities (*WR* record)
- Monthly, seasonal, or annual limits on diversions, stream flow depletions or withdrawals from storage (supplemental options *SO* record, stream flow depletion limit options *LO* record, and monthly varying limits on depletions *ML* record)
- Secondary backup right that supplies shortages incurred by other rights (backup *BU* record)
- Diversions or releases from reservoir storage (water right storage *WS* record, operating rules *OR* record, and monthly storage capacity limits *MS* record)

## Return Flows and Conveyed Flows in the SIM Simulation

- Return flows can be portions of withdrawals from surface (WR record) or ground (CI record) water sources discharged to a stream after use.
  - municipal/industrial wastewater treatment effluent
  - irrigation returns
- Return flows can also represent water transported through pipelines or canals.
- Releases through hydroelectric power turbines are also treated computationally as return flows.

## **Water Right WR Record** (Users Manual Pages 69-71)

CP – control point identifier
AMT – annual diversion or hydroelectric energy target
USE – use type identifier (or blank, LDAYS, NDAYS, XMONTH)
WRNUM(wr,7) – priority number
WRNUM(wr,5) – water right type (type 4 inflow to river system)
RFMETH – return flow methods (same/next month; constant/monthly)
RFAC – constant return flow factor
RFIDWR – identifier on RF record for monthly factors
RCP – control point to return flow with default of next downstream
FSCV – identifier of flow switch FS or cumulative volume CV record
DINDEX – drought index identifier
WRID, WRIDS1, WRID2 – water right and group identifiers

## **Location of Return Flows**

- The default WR record RFMETH(wr) option is to discharge return flows at the next downstream control point.
- Any downstream or upstream control point can be specified as RCP on the WR record, even in another river basin within the simulation model.

## Timing of Return Flows

(WR Record RFMETH Options)

Option 1 – The default option is to discharge the return flows in the same month as the diversion.

Option 2 - Return flows can also be discharged in the next month of the simulation at the beginning of the priority sequence allowing senior water rights access to the return flows.

## Return Flow as Percentage of Diversion

Return Flow = Factor x Diversion Amount

- A constant return flow factor RFAC entered on the WR record can be used for all months.
- Return flow factors can be specified for each of the 12 months of the year on RF records referenced to WR records by identifier RFIDWR.

### CI Record – Constant Inflows or Outflows for Each of the 12 Months of the Year

(Users Manual Page 66)

CIID – control point identifier
CI(M=1,12) – Flow added to naturalized flow at control point CIID in each of the 12 months of the year

### FA Record – Adjustments to Naturalized Flows

(Users Manual Page 48 and 127-128)

Flow adjustments vary throughout the hydrologic period-of-analysis.

### Hydroelectric Energy Generation

- WR record type 5 and type 6 water rights generate hydroelectric energy. Monthly hydroelectric energy generation targets in megawatt-hours are set similarly to monthly water supply diversion targets in acre-feet.
- A hydropower HP record for a WR record water right provides input regarding hydraulic-to-electric efficiency, tailwater elevation, turbine invert elevation and discharge capacity, and a maximum limit on secondary energy generation.

## HP Record – Hydroelectric Power
(Users Manual Page 80)

WRSYS(9) – energy efficiency factor (default = 0.85)

WRSYS(10) – tailwater discharge-elevation from TQ/TE records or constant tailwater elevation

TELEV – turbine inlet invert elevation (default inactive pool)

TQCA – turbine discharge capacity

TPCAP – maximum limit on energy production

## Hydropower Equation (Reference Manual Pages 96-101)

**E = Q H e t (*POWFCT*)**

E = P t

P = $\gamma$ Q H e (unit conversion factors)

energy (E) in megawatt-hours (MW-hrs)
discharge (Q) in acre-feet/month
head (H) in feet
efficiency (e) is dimensionless fraction less than 1.0
time (t) is a month
power (P) in Watts [Watt = Nm/s, MW = 1,000,000 W]
*POWFCT* = (unit weight of water ($\gamma$)) (conversion factors)
*Default POWFCT* = 0.0010237
Values of *POWFCT* for other units are tabulated in Table 4.2 on page 99.

## SO Record Supplemental Water Right Options

(Reference Manual Pages 120, 138-139; Users Manual Pages 90-93)

WSHED – option for limiting stream flow availability

MONDEP – limit on monthly stream flow depletions

ANNDEP – annual or seasonal limit on stream flow depletions

ACPID – alternative control point for stream flow depletions

BACKUP – backup right [replaced by BU record (page 106)]

MRW – monthly limit on withdrawals from reservoir storage

ARW – annual or seasonal limit on withdrawals from reservoir storage

ISHT – which targets and shortages are recorded in output file

ADL – annual or seasonal diversion or instream flow limits

LM(1) and LM(2) –months covered by season limits

NOTFLAG – options to not apply certain feature for this water right

DUAL(WR) – dual simulation option (same as PX record field 2)

## Maximum Limits on Stream Flow Depletions Taken by a Water Right

Supplemental Options SO Record MONDEP and ANNDEP Options

ML Record – Monthly-Varying Limits on Stream Flow Depletions

LO Record – Stream Flow Depletion Limit Options

The LO record is identical to the TO record except maximum limits on stream flow depletions are computed rather than water right targets.

## Example 2 on pages 394-398 of Reference Manual Appendix C

```
** Res B is located at CP5 and is filled from streamflow at CP4 as well as CP5.
** WR3a includes both storage in Res B and a 20 ac-ft/month diversion at CP5.
** WR3b allows filling of Res B at CP5 by depleting streamflows from CP4.
** The CP4 streamflow depletion has both monthly and annual limits.
**
WR   CP5      240   const    8888                                WR3a
WS Res B      100     0.1       1    0.0
WR   CP5        0   const    9999                                WR3b
WS Res B      100
SO                    350     CP4
ML     5      0      0      5     15     15    200    200    200    200    200    200
```

Supplemental Options SO Record is explained on Users Manual pages 90-93.
Monthly-Varying Limits on Stream Flow Depletions ML Record is explained on Users Manual page 97.

## Backup Water Right

(Reference Manual Page 137 and Users Manual Page 106)

Diversion, instream flow, or hydropower shortages incurred by one or more water rights may be supplied by another water right called a backup right employing a BU records.

The input parameter BACKUP in SO record field 6 is superseded by the more recently added BU record.

## BU Record – Backup Right
(Users Manual Page 106)

BU – step in target building process where back-up is applied

BUX – factor by which the shortage is multiplied (default = 1.0)

BUWRID – identifier of water right being backed up

BUG – group of water rights being backed up

## Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

## Course Modules

1. Simulation of Water Supply, Hydroelectric Energy Generation, and Instream Flow Requirements
2. Setting Water Supply, Hydroelectric Energy, and Instream Flow Targets
3. River/Reservoir System Operations for Meeting the Targets (this module)
4. SIM Options for Simulating Reservoir Operations (the next module)

## Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

## Module 4 – SIM Options for Simulating Reservoir Operations

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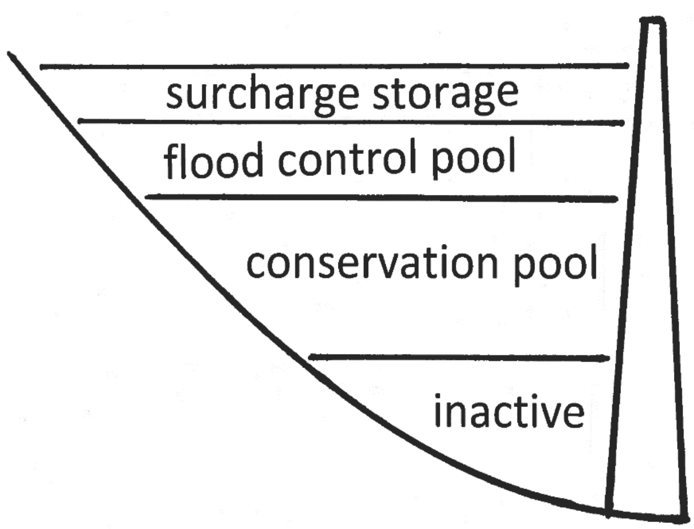
Sponsored by the
Texas Commission on Environmental Quality

May 2021

### Vertical Storage Zones or Pools

Flood control and surcharge pools are simulated in the daily SIMD but not the monthly SIM.



# Reservoirs in Texas

Storage and Regulation of River Flows by Dams and Reservoirs,
by R. Wurbs, *Texas Water Journal*, 12(1):10-39, 2021.

- About 3,450 reservoirs in the 20 WAMS (No flood control)

  210 reservoirs ≥ 5,000 acre-feet (98% total)
  80 reservoirs ≥ 50,000 acre-feet (92% total)

- 27 Largest Reservoirs (≥ 500,000 ac-ft including FC)

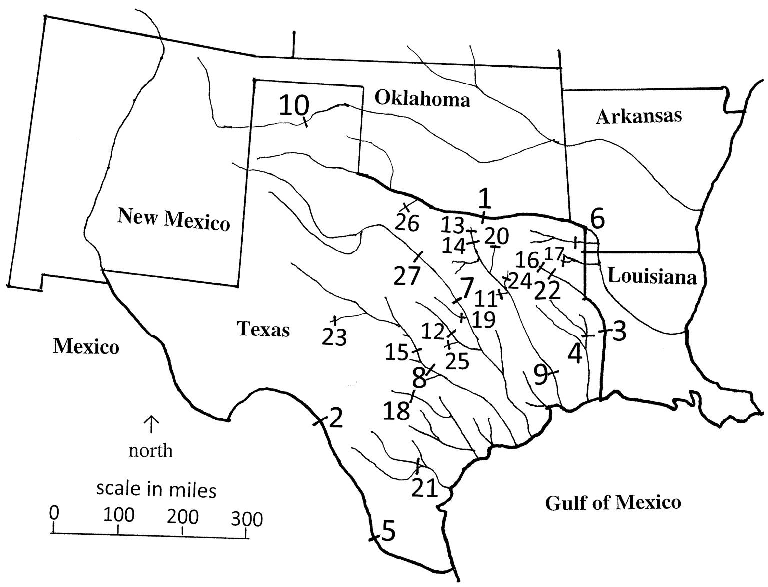
  Total Capacity 27 Reservoirs: 44,747,000 ac-ft (78%)
  Conservation: 28,990,000 ac-ft (71%)
  Flood Control: 15,757,000 ac-ft (97%)

- The many reservoirs not included in the WAMs include:

  2,000 NRCS flood retarding dams in Texas
  numerous urban stormwater detention basins
  many small farm/ranch ponds and recreation ponds

## Reservoirs with Storage Capacities Exceeding 500,000 acre-feet

| | Reservoir | River of Dam | Owner | Initial Storage | Area (acres) | Storage Capacity (acre-feet) Conservation | Flood Contr | Total |
|---|---|---|---|---|---|---|---|---|
| 1 | Texoma | Red River | USACE Tulsa | 1943 | 78,400 | 2,441,000 | 2,660,000 | 5,101,000 |
| 2 | Amistad | Rio Grande | IBWC | 1968 | 66,500 | 2,977,000 | 1,744,000 | 4,721,000 |
| 3 | Toledo Bend | Sabine River | SRA | 1966 | 182,500 | 4,453,000 | – | 4,453,000 |
| 4 | Sam Rayburn | Angelina River | USACE | 1965 | 112,600 | 2,888,000 | 1,099,000 | 3,987,000 |
| 5 | Falcon | Rio Grande | IBWC | 1953 | 85,200 | 2,648,000 | 910,000 | 3,558,000 |
| 6 | Wright Patman | Sulphur River | USACE FW | 1956 | 18,200 | 145,000 | 2,509,000 | 2,654,000 |
| 7 | Whitney | Brazos River | USACE FW | 1951 | 23,200 | 561,000 | 1,372,000 | 1,933,000 |
| 8 | Travis | Colorado River | LCRA | 1940 | 19,000 | 1,132,000 | 779,000 | 1,911,000 |
| 9 | Livingston | Trinity River | TRA | 1969 | 32,600 | 1,740,000 | – | 1,740,000 |
| 10 | Meredith | Canadian River | CRMWD | 1941 | 16,400 | 808,000 | 543,000 | 1,351,000 |
| 11 | Richland-Chambers | Richland Creek | Tarrant RWD | 1987 | 43,400 | 1,109,000 | – | 1,109,000 |
| 12 | Belton | Leon River | USACE FW | 1954 | 12,100 | 433,000 | 640,000 | 1,073,000 |
| 13 | Ray Roberts | Elm Fork Trinity | USACE FW | 1987 | 28,600 | 796,000 | 265,000 | 1,061,000 |
| 14 | Lewisville | Elm Fork Trinity | USACE FW | 1954 | 27,200 | 614,000 | 363,000 | 977,000 |
| 15 | Buchanan | Colorado River | LCRA | 1937 | 22,100 | 889,000 | – | 889,000 |
| 16 | Tawakoni | Sabine River | SRA | 1960 | 37,300 | 885,000 | – | 885,000 |
| 17 | Lake O' the Pines | Cypress Creek | USACE FW | 1957 | 16,900 | 241,000 | 587,000 | 828,000 |
| 18 | Canyon | Guadalupe River | USACE FW | 1964 | 8,310 | 372,000 | 395,000 | 767,000 |
| 19 | Waco | Bosque River | USACE FW | 1965 | 8,190 | 207,000 | 506,000 | 713,000 |
| 20 | Lavon | East Fork Trinity | USACE FW | 1953 | 20,600 | 419,000 | 292,000 | 711,000 |
| 21 | Choke Canyon | Frio River | Corpus Christi | 1982 | 26,000 | 693,000 | – | 693,000 |
| 22 | Lake Fork | Lake Fork Cr | SRA | 1979 | 27,300 | 636,000 | – | 636,000 |
| 23 | Twin Buttes | South Concho | San Angelo | 1962 | 8,450 | 178,000 | 454,000 | 632,000 |
| 24 | Cedar Creek | Cedar Creek | Tarrant RWD | 1965 | 1,560 | 631,000 | – | 631,000 |
| 25 | Stillhouse Hollow | Lampasas River | USACE FW | 1968 | 6,480 | 224,000 | 391,000 | 615,000 |
| 26 | Kemp | Wichita River | Wichita Falls | 1922 | 15,400 | 318,000 | 248,000 | 566,000 |
| 27 | Possum Kingdom | Brazos River | BRA | 1941 | 16,700 | 552,000 | – | 552,000 |




## Institutional Framework for Reservoir Management

- International Boundary and Water Commission (IBWC)
- Federal Reservoir Owners
  - U.S. Army Corps of Engineers (USACE)
  - Natural Resource Conservation Service (NRCS)
  - U.S. Bureau of Reclamation (USBR)
- Non-Federal Reservoir Owners
  - River Authorities
  - Water Districts
  - Cities
  - Electric Power Companies
- Texas Commission on Environmental Quality (TCEQ)
- Texas Water Development Board (TWDB)

## Simulation of Reservoirs

- WR record rights refill reservoir storage and divert or release water from reservoirs. Releases can also be used to supply IF record instream flow requirements. Only WR record type 1 or 3 rights or IF record rights can refill reservoir storage.
- Each reservoir is associated with at least one WR or IF record and only one CP record.
- Multiple WR and IF records with different priorities can have access to the same reservoir.
- Total storage capacity and inactive storage capacity from WS records may vary between water rights at the same reservoir.
- Multiple reservoirs may be assigned to the same control point.
- Flood control storage is included in the daily SIMD but not the monthly SIM. Otherwise, daily and monthly simulation computations for reservoirs are basically the same.

**SIM Input Parameters Controlling Reservoir System Operations** (Table 4.6 Page 140)

| Record Field | Description of Input Parameter |
|---|---|
| WR field 6 | Selection between the water right types defined in Tables 4.1 and 4.5. |
| WS field 3 | Total reservoir storage capacity at top of conservation pool in acre-feet. |
| WS field 7 | Reservoir storage capacity at top of inactive pool in acre-feet. |
| WS field 8 | Storage contents at the beginning of the simulation. Default is full reservoir. |
| WS fields 4,5,6 | Specification of storage volume versus surface area relationship. |
| WS fields 9, 10 | Evaporation allocation option for multiple owner reservoir. |
| WS field 11 | Downstream releases accessible to hydropower versus lakeside withdrawals. |
| SV/SA records | Table of storage volume in acre-feet versus surface area in acres. |
| EA/EF records | Net evaporation-precipitation allocation for multiple-owner reservoirs. |
| OR field 3 | Storage capacity at top of zone 2 (bottom of zone 1). Default = inactive |
| OR field 4 | Multiplier factor (M) in Equations 4.6 and 4.7 for zone 1. Default = 1.0 |
| OR field 5 | Multiplier factor (M) in Equations 4.6 and 4.7 for zone 2. Default = 1.0 |
| OR field 6 | Selection between rank index Equations 4.6 and 4.7. Default is Eq. 4.6. |
| PE/PV records | Elevation versus volume table used with rank index Equation 4.7. |
| JO field 11 | Beginning versus end-of-period storage for multiple-reservoir release rules. |
| JO field 8 | Options to match beginning and end of simulation storage contents. |
| OR field 8 | Storage capacity in ac-ft at bottom of upper sub-pool. Default is no sub-pool. |
| OR field 9 | Rank index for upper sub-pool. Default = 1.0 |
| OR field 10 | Storage capacity in acre-feet at top of lower sub-pool. Default is no sub-pool. |
| OR field 11 | Rank index for upper sub-pool. Default = 1.0 |
| OR field 12 | Monthly reservoir release limit in acre-feet. Default is no release limit. |
| OR fields 13, 14 | Options for using CV or FS record to compute monthly release limit. |
| OR field 7 | Pump and pipeline versus downstream gravity flow releases from reservoir. |
| MS record | Monthly storage capacity limits defining seasonal rule curve operations. |
| OF field 2 | System operation tracking variables are recorded in the SIM DSS output file. |
| JO field 10 | Hydropower and system releases in HRR file read by TABLES 4HRR. |

## **Water Right WR Record** (Users Manual Pages 69-71)

CP – control point identifier
AMT – annual diversion or hydroelectric energy target
USE – use type identifier (or blank, LDAYS, NDAYS, XMONTH)
WRNUM(wr,7) – priority number
WRNUM(wr,5) – water right type (Default is type 1.)
RFMETH – return flow specifications
RFAC – constant return flow factor
RFIDWR – identifier on RF record for monthly factors
RCP – control point to return flow with default of next downstream
FSCV – identifier of flow switch FS or cumulative volume CV record
DINDEX – drought index identifier
WRID, WRIDS1, WRID2 – water right and group identifiers

## **WR Record Water Right Types**

(Reference Manual Pages 86-89 and Users Manual Pages 69-71)

Type 1 – Access first to stream flow and then to reservoir storage. Reservoir storage refilling after meeting the diversion target.

Type 2 – Same as Type 1, except that no storage refilling is allowed.

Type 3 – Only releases from reservoir storage; no stream flow depletions and no refilling storage.

Type 4 – Inflow discharged to the river system.

Type 5 – Hydropower equivalent of Type 1.

Type 6 – Hydropower equivalent of Type 3.

Type 7 – Sets reservoir storage capacity (storage target).

Type 8 – Target computed for use with FS and TO records.

## Primary and Secondary Reservoirs

- A water right can be associated with any number of reservoirs. Any number of water rights can be associated with the same reservoir.
- Storage is refilled in reservoirs only by a WR record type 1 water right or IF record right. A single water right can refill storage in only one reservoir (called the primary reservoir) but can divert or release water from any number of secondary reservoirs.
- The WR record type 1 water right and its primary reservoir must be located at the same control point.
- WR record types 2 and 3 rights can only divert or release from reservoirs. Only WR record type 1 rights can refill storage.

## Off-Channel Reservoirs

- Regular “on-channel” reservoirs are impounded by a dam across a river or stream. The inflows of from the streams flowing into the reservoir are stored and released or withdrawn as needed.
- Off-channel reservoirs are filled by pumping water from a river or stream but are not located on that river or stream.
- Off-channel reservoirs are modeled in SIM identically the same as on-channel reservoirs with the exception that a pumping or conveyance capacity may be specified for a off-channel reservoir.

## Maximum Limits on Stream Flow Depletions Taken by a Water Right

Supplemental Options SO Record MONDEP and ANNDEP Options

ML Record – Monthly-Varying Limits on Stream Flow Depletions

LO Record – Stream Flow Depletion Limit Options

The LO record is identical to the TO record except maximum limits on stream flow depletions are computed rather than water right targets.

## Input Parameters Specified on WS Record Reservoir Storage Associated with a Water Right

(Users Manual Pages 82-83)

RES – reservoir identifier

WRSYS- total storage capacity at top of conservation pool

A, B, and C for area = $A(\text{storage})^B + C$

Default is SV/SA record storage/area table

INACT – storage capacity at top of inactive pool

BEGIN – beginning storage with default of capacity

IEAR, SA – evaporation allocation EA record option

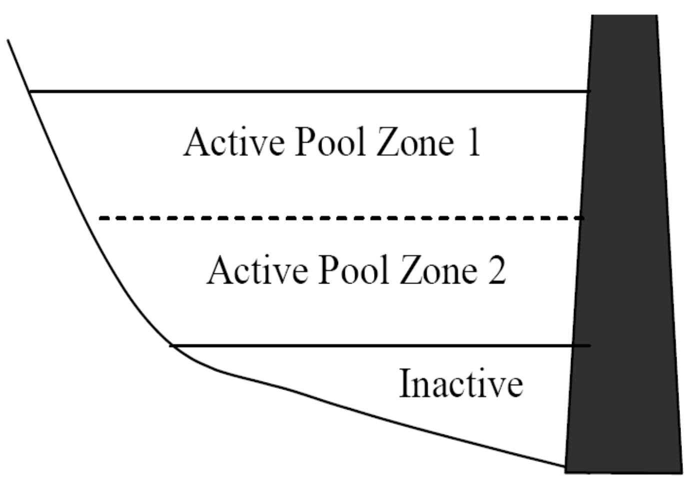
LAKESD – whether water supply diversions are or discharged through hydropower turbines

## OR Record – Operating Rules for Secondary Reservoirs

- Control point identifier of reservoir location. Default is control point for the reservoir which has been assigned by a prior right.
- Storage capacity at top of zone 2 (bottom zone 1). Default is inactive storage from WS record.
- Zones 1 and 2 multiplier factors M. Default is 1.0
- Choice of storage volume (Eq. 3.1) or drawdown depth (Eq. 3.2) rank index equation. Default is rank index equation (Eq. 3.1).
- Pump/pipeline conveyance option or gravity flow only. Default is only gravity flow in stream channels.
- Upper and lower sub-pool storage capacities. Default is option not used.
- Rank indices for upper and lower sub-pools. Default is 1.0
- Monthly release limit. Default is the option is not used.
- Identifier of CV or FS release limit. Default is the option is not used.

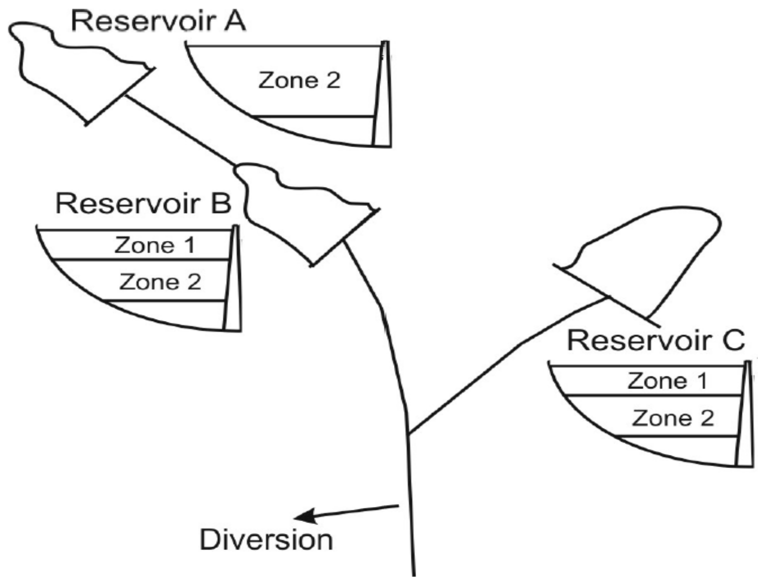
## Storage Zones Defined By Operation Rules OR Record for Multiple-Reservoir System Operations

(Figure 4.1 on Page 144 of Reference Manual and Figure 3.1 on Page 84 of Users Manual)



## OR Record Storage Zones in System Reservoirs

(Figure 4.2 on Page 144 of Reference Manual)




## Default Rank Index Equation 3.1 Based on Storage for Multiple-Reservoir System Operations

The operating rules *OR* record includes an input multiplier factor (*M*) used in the simulation to compute a rank index used to determine the reservoir from which to release in each time period.

$$Rank\ Index = M\left[\frac{storage\ content\ in\ zone}{storage\ capacity\ of\ zone}\right]$$

## Default Rank Index Equation 3.2 for Multiple-Reservoir System Operations Based on Draw-Down Depth

OR Record on Users Manual Pages 84-86
OR Record Field 6 Selection of Eq. 3.1 or Eq. 3.2

Rank Index = (-1.0) x (drawdown depth)

**Example 3 in Reference Manual Appendix C** (Pages 387-393)

```
JD      2     2008        1       -1       -1
JO      4
XL                                             1.0237
RO      1     RES3
**
**  Monthly Use Factors
**
UC    MUN     0.06     0.06     0.07     0.07     0.08     0.10
UC            0.13     0.12     0.09     0.08     0.08     0.06
UC IRRIG         0        0        0        0     0.25     0.25
UC            0.25     0.25        0        0        0        0
**
**  Control Point Records
**
CP    CP1      CP3
CP    CP2      CP3         0.08333
CP    CP3      CP4                                          NONE
CP    CP4      CP6                                           CP1
CP    CP5      OUT    0.811                                  CP1
CP    CP6      OUT                                          NONE
**
```

## Continuation of DAT File for Example 3 from Reference Manual

```
**   Water Rights and Associated Reservoirs
**   Water Right IF2  ----------------------------------------------
IF   CP6     240            191803                              IF2
**   Water Right IF1  ----------------------------------------------
IF   CP3     120            191805                              IF1
**   Water Right WR1  ----------------------------------------------
WR   CP1     360.           192602    1          .2                WR1
WS   RES1    200.      .1       1.       0.      10.
**   Water Right WR2  ----------------------------------------------
WR   CP2      60.    IRRIG  193908    1          .2                WR2
WS   RES2     50.      .1       1.       0.      25.
**   Water Right WR3  ----------------------------------------------
WR   CP2     180.           196506    1          .2                WR3
WS   RES2    250.      .1       1.       0.      25.
**   Water Right WR4  ----------------------------------------------
WR   CP3     720.      MUN  195207    2          0.4               WR4
WS   RES2    250.                                25.
OR           125.       1        1
WS   RES1    200.                                10.
OR           200.       0        1
```

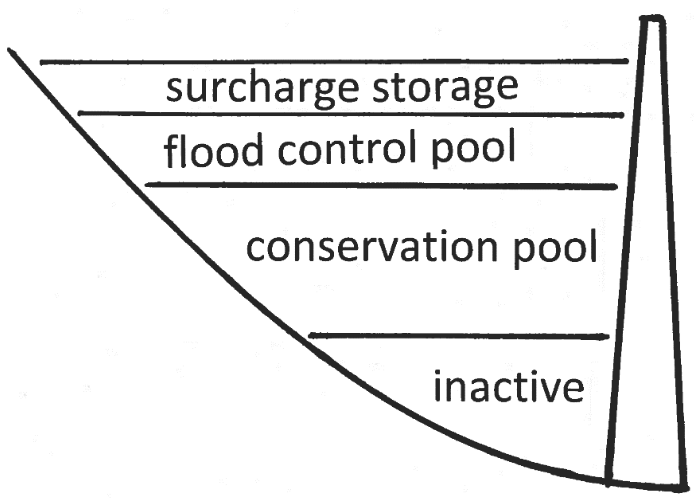
## Continuation of DAT File for Example 3 from Reference Manual

```
**   Water Rights WR5a and WR5b  ------------------------------------
WR    CP5       0.          196213    1                             WR5b
WS   RES4     200.      -1                           100.
WR    CP5     600.          196212    2                             WR5a
WS   RES4     200.      -1
OR            100.       1        1      -1
WS   RES3     300.      .1       1.      0.     150.
OR    CP4     300.       1        1      -1
**   Water Right WR6  -----------------------------------------------
WR    CP4     120.          195704    2                             WR6
WS   RES3     300.      .1       1.      0.      30.
**   Water Right WR7  -----------------------------------------------
WR    CP4   12000.          197801    5                             WR7
WS   RES3     300.                               30.
HP   0.85       5.
```

## Continuation of DAT File for Example 3

```
**   Water Right WR8  ---------------------------------------------
WR    CP6     400.   IRRIG  197412   3   2                      WR8
WS   RES2     250.                             25.
OR            125.        1       1
WS   RES1     200.                             10.
OR            200.        0       1
WS   RES3     300.       .1       1.      0.   30.
OR            165.        1       1
**
**   Storage versus Area Table for Reservoir RES4
**
SV   RES4       0.     200.
SA              0.      20.
**
**   Storage versus Elevation Table for Reservoir RES3
**
PV   RES3       0.     300.
PE              0.     100.
**
ED
```

## Seasonal Rule Curve Operations Simulated with a MS Record



## MS Record – Monthly Storage Capacity Limits

RES – reservoir identifier

STMON(M=1,12) – maximum storage volume in each month

STMON(13) – maximum monthly release volume

## Multiple Rights for Water Supplied from the Same Reservoir

The last two topics covered in this course module deal with two different complexities of modeling multiple water rights that share the same reservoir.

1. The evaporation allocation EA record provides options for allocating reservoir net evaporation-precipitation to component computational reservoirs used to model multiple water rights that share the same reservoir.
2. The dual simulation option controlled by the PX record input parameter DUAL deals with the issue of senior rights refilling storage depleted by junior rights.

## EA Record – Net Evaporation-Precipitation Allocation
## EF Record – Net Evaporation-Precipitation Allocation Factors

(Users Manual Pages 117-119)

EA Record

NEA – EA integer identifier

NEAF – allocation method

EARES – reservoir identifiers

EF Record

EAO – options for applying factors

EAL – fractional storage limit switch

EAF – factors for the reservoirs on the EA record for allocation option based on factors used with NEAF options 3 and 4.

## Allocation of Evaporation-Precipitation Volume between Computational Component Reservoirs

The EA record provides the following alternative methods for allocating evaporation-precipitation volume between component reservoirs used to model multiple water rights sharing the same single actual reservoir.

1. Incremental based on water right priorities.
2. Based on beginning-of-month storage content.
3. Based on factors input on EF records.
4. Combination of options 1 and 3.

## AF Record – Stream Flow Availability Allocation Factors
(Users Manual Pages 117-119)

The AF record is designed for allocating available stream flow between multiple water rights that share the same priority.

AFMIN - Minimum available stream flow for any reservoir

AFMAX – maximum available stream flow for any reservoir

AFX(I) – factors for the reservoirs listed on the EA record by which available stream flow is multiplied

## Example 6 Modeling a Multiple-Owner Reservoir
(Reference Manual Appendix C Pages 420-424)

**DAT File with Reservoir without EA, EF, and AF Records**

```
JD      2    2015       1       -1       -1
JO      3
CP    CP1
WR    CP1  300000               1                     WR-1B
WS  Res-A  500000
SV  Res-A        0  100000  200000  400000  500000
SA               0   10000   20000   40000   50000
ED
```

## Example 6 in Reference Manual Appendix C (Page 422)

```
JD     2    2015       1      -1      -1
JO     3
CP   CP1
WR   CP1  120000              1                                WR-1
WS Res-A  200000                                              1
WR   CP1  120000              2                                WR-2
WS Res-B  200000                                              1      -1
WR   CP1   60000              3                                WR-3
WS Res-C  100000                                              1      -1
SV Res-A       0  100000  200000  400000  500000
SA             0   10000   20000   40000   50000
** 40%, 40%, and 20% of both net evaporation and available streamflow
** are allocated to component reservoirs Res-A, Res-B, and Res-C.
EA     1       3   Res-A   Res-B   Res-C
EF     0       0     0.4     0.4
AF     0       0     0.40.666667     1.0
ED
```

## Dual Simulation Option Activated by Input Parameters DUALD (default) on JO Record and DUAL (individual rights) on PX Record

(Reference Manual Pages 155-157
and Users Manual Pages 42-44 and 107-109)

The dual option performs the simulation twice with user-specified water rights included or excluded in each of the two simulations. Streamflow depletions computed in the first simulation are employed as maximum limits on streamflow depletions during the second simulation. The main reason for the dual option is to prevent junior rights from diverting water from storage refilled by senior rights at the same reservoir.

## Dual Simulation Options

Option 1: The water right is activated only during the initial simulation.

Option 2: The water right is activated only during the second simulation and is not subject to an initial simulation stream flow depletion constraint.

Option 3 with variations 33 and 333: A dual simulation is automatically performed. Stream flow depletions computed during the first simulation serve as upper limits on water availability during the second simulation. The stream flow depletions computed during the initial simulation may optionally be written to the message file.

Option 4: The water right is activated only during the initial simulation. A stream flow depletion array is developed. If an option 5 right follows this right, the depletions serve as upper limits on water availability for the option 5 right during the second simulation. The stream flow depletions may optionally be written to the message file.

Option 5 with variations 55 and 555: A dual simulation is performed with this water right being activated only during the second simulation. The stream flow depletion array from the preceding option 4 right serves as an upper limit on depletions for this option 5 right.

## Modules of Course on Simulating Water Resources Development, Allocation, Management, and Use as WRAP Water Rights

1. Simulation of Water Supply, Hydroelectric Energy Generation, and Instream Flow Requirements
2. Setting Water Supply, Hydroelectric Energy, and Instream Flow Targets
3. River/Reservoir System Operations for Meeting the Targets
4. SIM Options for Simulating Reservoir Operations

## Short-Term Conditional Reliability Modeling

## Module 1 – Basics of Conditional Reliability Modeling

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Sponsored by the
Texas Commission on Environmental Quality

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## Modules for WRAP Online Course on Short-Term Conditional Reliability Modeling

Module 1 - Basics of Conditional Reliability Modeling (CRM)
[SIM CR Input Record and TABLES 5CRM Record]

Module 2 - Probability and Correlation Methods
[TABLES 5CR1, 5CR2, and 5COR Records]

## Documentation of Conditional Reliability Modeling (CRM) Features of WRAP

Reference Manual, Pages 265-342,
*Chapter 8 Short-Term Conditional Reliability Modeling*

Users Manual, Chapter 3 SIM Input Records, Page 54,
*CR Record – Conditional Reliability Modeling*

Users Manual, Chapter 5 Program TABLES, Pages 226-233,
*5CRM, 5CR1, 5CR2, and 5COR Records*

## Conditional Reliability Modeling (CRM)

Short-term Frequency and/or Reliability Analyses
Conditioned on Preceding Reservoir Storage

1. The hydrologic period-of-analysis is divided within SIM into many shorter simulation sequences as specified by a CR record inserted in the DAT file. Simulations with the multiple hydrologic sequences are automatically repeated by SIM with each sequence beginning with the same initial reservoir storage contents.
2. CRM is performed with SIM with the same input dataset as a conventional simulation, with the exception that a CR record is added to the DAT file. Results are recorded by SIM in an output file with filename extension CRM (rather than OUT) and the DSS file.
3. The majority of TABLES capabilities are applicable to either CRM or conventional simulations, but results are interpreted differently. CRM options are controlled with 5CRM, 5CR1, 5CR2, and 5COR records.

## Conventional versus CRM Simulations

- Conventional long-term WRAP simulation studies are designed for assessing the likelihood of meeting water supply, instream flow, and reservoir storage requirements in any randomly selected month or year without considering current reservoir storage conditions.
- Short-term CRM studies estimate the likelihood of meeting water supply, instream flow, and reservoir storage requirements in the near future, which is highly dependent on current reservoir storage levels. CRM analyses may be applied to forecast conditions one month, several months, a year, or perhaps more than a year into the future. There is no precise definition or time duration limit to the term "*short-term*".

## Conditional Reliability Modeling (CRM) Applications

- Planning studies to establish operating policies or drought contingency plans.
- Reoccurring operational planning activities.
- Real-time decision support during drought.

## Conditional Reliability Modeling (CRM) Procedures

- Defining simulation sequences and performing simulations for each sequence in *SIM*.
- Assigning probabilities to each sequence and performing frequency and reliability analyses with *TABLES*.

## Alternative CRM Strategies for Assigning Probabilities to Simulation Sequences within TABLES

1. Equal-Weight (5CRM Record) [Course Module 1]
2. Probability Array (5CR1 and 5CR2 Records) [Module 2]
   - Storage-Flow-Frequency (SFF) Array
   - Flow-Frequency (FF) Array

Correlation analyses of storage versus naturalized flow may be performed to help determine whether the additional complexity of the probability array methods are warranted. [Course Module 2]

## Reliability and Frequency Metrics Conditioned on Preceding Reservoir Storage

Capabilities for supplying water supply and hydropower targets, meeting instream flow targets, and refilling reservoir storage over the next several months depend upon:

1. the amount of water currently available in reservoir storage
2. hydrology that occurs over the future several-month period of interest as represented by monthly naturalized stream flow and net reservoir evaporation-precipitation rates

## Equal-Weight and Probability Array Strategies for Assigning Probabilities to Simulation Sequences

Equal-Weight Strategy

Frequency and reliability analyses are based simply on treating each simulation sequence as one possibility out of the total number of simulation sequences. The SIM CR record and TABLES 5CRM record are the only additional input records.

Probability Array Strategy Based on FF or SFF Relationships

The simulation sequences are assigned probabilities that vary between the different sequences in TABLES using methods controlled by 5CR1 and 5CR2 records.

## FF and SFF Versions of Probability Array Strategy for Assigning Probabilities to Simulation Sequences Using Sets of Options on 5CR1 and 5CR2 Records

- The flow frequency (FF) relationship based methodology is based on assigning exceedance probabilities directly to naturalized flow volumes using either the log-normal probability distribution or Weibull formula. Preceding reservoir storage may be either ignored or incorporated using only sequences with preceding storage falling within a specified range.
- The storage-flow-frequency (SFF) relationship based methodology is based on probabilistically representing deviations in naturalized flow volumes from the amounts indicated by a regression relationship between naturalized stream flow volume and either preceding reservoir storage volume or change in preceding storage volume.

## Beginning-of-Simulation Storage Content Options in Both Conventional Long-Term SIM Simulation and CRM

- The default sets beginning-of-simulation storage contents equal to conservation storage capacity.
- Entries for BEGIN in WS record field 8 sets beginning-of-simulation storage contents for individual water rights.
- BES and BRS options in JO record fields 8 and 9 create and read files of the beginning-of-simulation storage contents for all reservoirs.
- CR4 in CR record field 5 is a multiplier factor by which all beginning-of-simulation storage contents are multiplied (default = 1.0).

## CR Record – Conditional Reliability Modeling
(Users Manual Page 54)

CD – CR record identifier

CR1 – Length of simulation period in months (Default = 12)

CR2 – Starting month for annual cycle option.
(Blank for monthly cycle.)

CR3 – CRM output options for CR1 greater than 12 months.

CR4 – Factor by which all starting storages are multiplied.

CR5 – Options for cyclic repetition of months
for CR1>12 and CR2>0

## Alternative CRM Strategies for Defining Simulation Sequences within SIM

CR1 in CR record field 2 is the length of the simulations in months.

CR2 in CR record field 3 defines the cycle organization for the annual or non-annual (monthly) cycle options as follows.

- **Annual cycle option** starts each simulation sequence in the same month (CR2 = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12).
- **Non-annual (monthly) cycle option** starts simulation sequences in different months which allows more sequences but does not reflect seasonality (CR2 = 0 or blank CR2 field).

## Example of Simulation Sequences for a Hydrologic Period-of-Analyses of 1940-2019 Employing the Annual Cycle Option Starting in June

CR1 = 12 months (default) and CR2 = 6 on CR Record

Sequence 1: June 1940 through May 1941
Sequence 2: June 1941 through May 1942
Sequence 3: June 1941 through May 1942

Sequence 4 through Sequence 78

Sequence 79: June 2018 through May 2019

With the annual cycle option, the sequence length (simulation period) CR1 can be any number of months. The starting month CR2 is either 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12.

## Hydrologic Period-of-Analyses of 1940-2013 Non-Annual (Monthly) Cycle Option

CR1 = 4 months and CR2 = 0 or blank on CR Record

Number of sequences = (12)(number of years) – CR1 +1
= (12)(74) – 4 + 1 = 885 sequences

First Cycle
Sequence 1: January 1940 through April 1940
Sequence 2: May 1940 through August 1940
Sequence 3: September 1940 through December 1940
Sequence 4: January 1941 through April 1941
Sequence 5 through Sequence 220
Sequence 221: May 2013 through August 2013
Sequence 222: September 2013 through December 2013

Cycles 2, 3, and 4 begin in February 1940, March 1940, and April 1940, respectively, and end in December 2013, October 2013, and November 2013.

**Example 8.3 Reference Manual Pages 293-299**

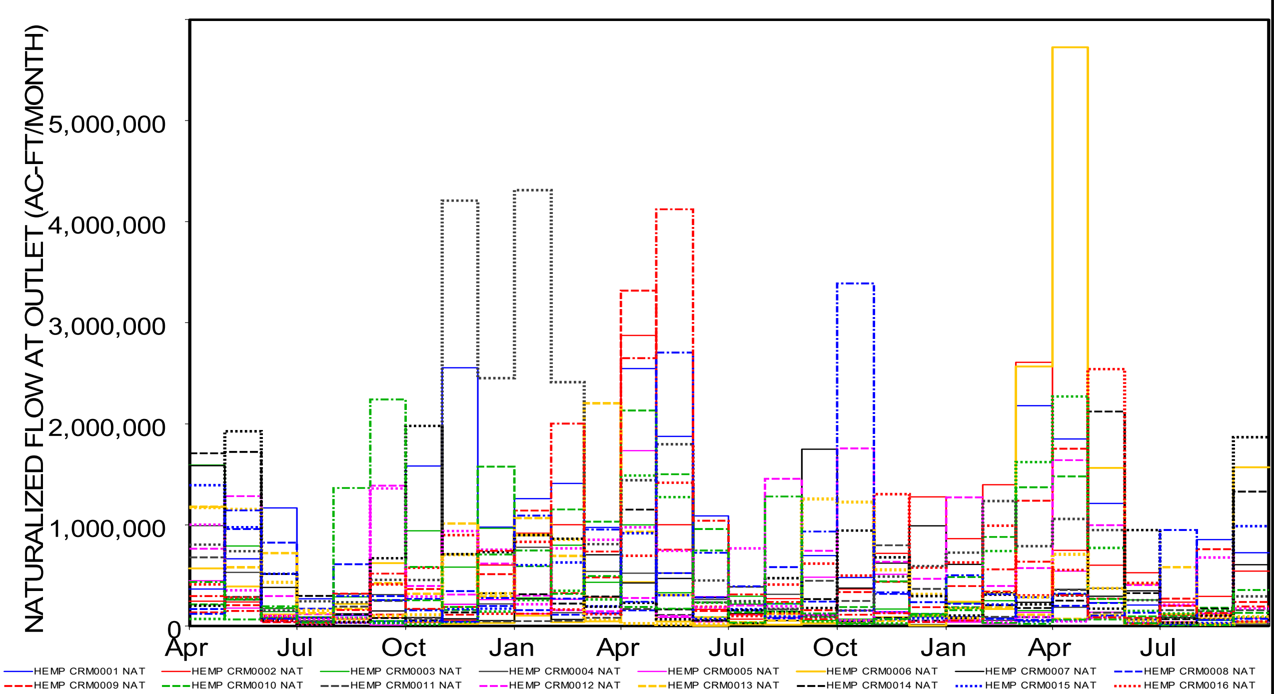
Figure 8.1 Naturalized Flows at Outlet with Twenty-Four 30-Month Sequences (Page 299)

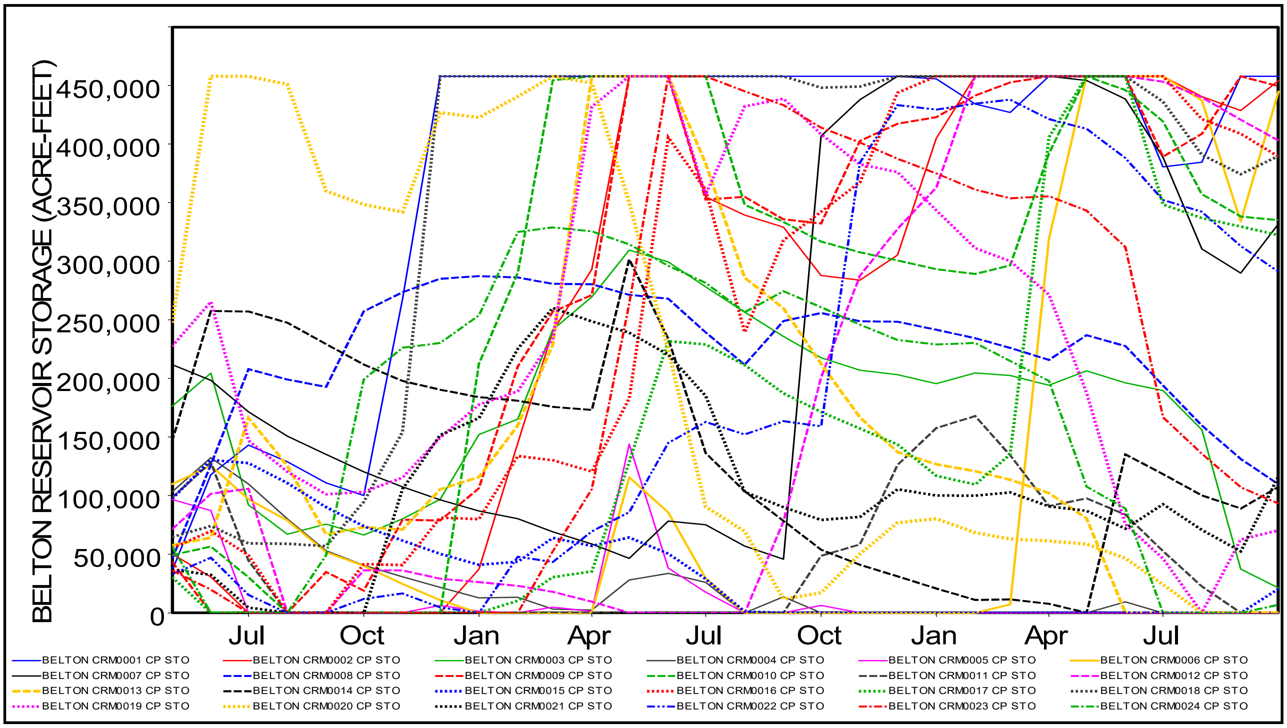
Figure 8.2 End-of-Month Storage Contents of Belton Reservoir with Twenty-Four 30-Month Sequences

1940-2013 hydrologic period-of-analysis (74 years).

Annual cycle with simulation length of 30 months beginning in May as defined by following CR record.

| CR | 30 | 5 | -1 | 0.10 | 2 |
|---|---|---|---|---|---|
| | CR1 | CR2 | CR3 | CR4 | CR5 |






## TABLES 5CRM Record
(Users Manual Page 226)

CD – 5CRM record identifier

CRHEAD – option to not insert CRM header at the top of each table
(The header is inserted by default.)

The 5CRM and 5CR2 (equal-weight and probability array options, respectively) records instruct TABLES to open a SIM simulation results CRM output file rather than OUT output file.

## TABLES Reliability and Frequency Analyses Performed with 2REL, 2FRE, 2FRQ, and 2RES Records

- TABLES input records and computations are the same with either CRM or conventional long-term simulation analysis, but the results are interpreted differently.
- Tables of volume and period reliabilities are created with 2REL records for either the entire period-of-analysis or a specified month of the year.
- Tables of frequency metrics are created with 2FRE records for either the entire period-of-analysis or a specified month of the year using optionally the basic relative frequency formula [F = (n/N)100%], Weibull formula [F = (n/(N+1))100%], or the normal or log-normal probability distribution.

## Reliability Summary for Selected Control Points

(Example 8.1, Table 8.6, Reference Manual Page 283)

**RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS**

**CONDITIONAL RELIABILITY MODELING: Equal-Weight Option**
**Annual cycles starting in month 4**
**Length of simulation period (CR1) is 12 months.**
**Number of simulations and months = 73 and 876 (CR3= 0)**
**Initial storage multiplier (CR4) = 0.250**

| NAME | TARGET DIVERSION (AC-FT/SQ) | MEAN SHORTAGE (AC-FT/SQ) | *RELIABILITY* PERIOD (%) | *RELIABILITY* VOLUME (%) | +++++++++ PERCENTAGE OF MONTHS +++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100% | 95% | 90% | 75% | 50% | 25% | 1% | -------- PERCENTAGE OF SEQUENCES -------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100% | 98% | 95% | 90% | 75% | 50% | 1% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PK | 254800.0 | 17265.32 | 90.30 | 93.22 | 90.3 | 90.4 | 90.5 | 91.4 | 92.7 | 93.9 | 97.6 | 67.1 | 67.1 | 69.9 | 75.3 | 86.3 | 100.0 | 100.0 |
| Whit | 18000.0 | 8904.52 | 52.28 | 50.53 | 52.3 | 52.3 | 52.3 | 52.4 | 52.5 | 52.6 | 52.7 | 8.2 | 8.2 | 8.2 | 24.7 | 38.4 | 47.9 | 83.6 |
| WacoL | 80800.0 | 128.13 | 99.66 | 99.84 | 99.7 | 99.7 | 99.7 | 99.8 | 99.8 | 99.9 | 100.0 | 97.3 | 98.6 | 98.6 | 98.6 | 100.0 | 100.0 | 100.0 |
| WacoG | 32300.0 | 4217.61 | 92.01 | 86.94 | 92.0 | 92.5 | 92.8 | 93.2 | 94.1 | 94.7 | 95.1 | 47.9 | 56.2 | 57.5 | 61.6 | 72.6 | 93.2 | 100.0 |
| High | 44800.0 | 7644.13 | 90.75 | 82.94 | 90.8 | 91.0 | 91.3 | 92.1 | 93.2 | 94.5 | 95.4 | 46.6 | 47.9 | 49.3 | 50.7 | 68.5 | 90.4 | 100.0 |
| Belton | 180260.0 | 20281.47 | 86.19 | 88.75 | 86.2 | 86.3 | 86.3 | 86.5 | 87.8 | 90.3 | 92.5 | 61.6 | 61.6 | 63.0 | 65.8 | 78.1 | 97.3 | 100.0 |
| George | 25610.0 | 4877.24 | 75.57 | 80.96 | 75.6 | 75.9 | 76.4 | 77.6 | 80.0 | 84.2 | 92.4 | 35.6 | 37.0 | 39.7 | 46.6 | 65.8 | 86.3 | 100.0 |
| Grang | 42000.0 | 5067.52 | 83.56 | 87.93 | 83.6 | 83.9 | 84.0 | 86.0 | 88.7 | 91.2 | 94.4 | 56.2 | 56.2 | 57.5 | 60.3 | 78.1 | 97.3 | 100.0 |
| Camer | 209600.0 | 42184.14 | 76.94 | 79.87 | 76.9 | 77.9 | 78.4 | 81.1 | 86.8 | 94.2 | 99.4 | 13.7 | 15.1 | 19.2 | 32.9 | 65.8 | 91.8 | 100.0 |
| Bryan | 98900.0 | 7761.60 | 84.13 | 92.15 | 84.1 | 84.4 | 85.0 | 91.4 | 98.1 | 99.1 | 99.3 | 37.0 | 41.1 | 53.4 | 64.4 | 93.2 | 100.0 | 100.0 |
| Hemp | 1119699.2 | 112197.34 | 77.28 | 89.98 | 77.3 | 79.3 | 82.2 | 89.6 | 91.9 | 95.2 | 99.7 | 26.0 | 43.8 | 57.5 | 68.5 | 84.9 | 97.3 | 100.0 |
| Total | 2106769.2 | 230529.02 | | 89.06 | | | | | | | | | | | | | | |

## Storage Frequency Tables
(Example 8.1, Table 8.8, Reference Manual Page 285)

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 6

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Number of simulations and months = 73 and 876 (CR3= 0)
Initial storage multiplier (CR4) = 0.250

| | | STANDARD | PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RESERVOIR | MEAN | DEVIATION | 100% | 99% | 98% | 95% | 90% | 75% | 60% | 50% | 40% | 25% | 10% | MAXIMUM |
| PK | 274433. | 192398. | 0. | 0. | 0. | 0. | 23638. | 107852. | 207815. | 250403. | 332598. | 431168. | 570240. | 570240. |
| Whit | 369903. | 158866. | 147820. | 149532. | 150368. | 173921. | 212404. | 231756. | 276234. | 331400. | 378941. | 498065. | 627100. | 627100. |
| WacoL | 120275. | 60465. | 35632. | 36624. | 37412. | 38335. | 42907. | 60685. | 94988. | 118444. | 150338. | 192100. | 192100. | 192100. |
| Belton | 206580. | 153073. | 0. | 0. | 0. | 0. | 39886. | 85882. | 115346. | 158477. | 216169. | 320874. | 457600. | 457600. |
| George | 16512. | 14472. | 0. | 0. | 0. | 0. | 0. | 3826. | 7309. | 12706. | 19454. | 34378. | 37100. | 37100. |
| Grang | 32147. | 26662. | 0. | 0. | 0. | 0. | 0. | 7815. | 15624. | 20741. | 47452. | 65500. | 65500. | 65500. |
| Total | 1019850. | 537902. | 188511. | 189331. | 190524. | 230428. | 380501. | 571751. | 788525. | 965851. | 1168131. | 1456516. | 1824394. | 1949640. |

## Storage Frequency Tables
(Example 8.1, Table 8.8, Reference Manual Page 285)

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 3

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Number of simulations and months = 73 and 876 (CR3= 0)
Initial storage multiplier (CR4) = 0.250

| | | STANDARD | PERCENTAGE OF MONTHS WITH VOLUME EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RESERVOIR | MEAN | DEVIATION | 100% | 99% | 98% | 95% | 90% | 75% | 60% | 50% | 40% | 25% | 10% | MAXIMUM |
| PK | 263996. | 191762. | 0. | 0. | 0. | 0. | 0. | 100990. | 202781. | 288471. | 328274. | 422820. | 564043. | 570240. |
| Whit | 480842. | 123476. | 224588. | 246840. | 255580. | 281222. | 332188. | 379000. | 411238. | 491683. | 541536. | 627100. | 627100. | 627100. |
| WacoL | 149334. | 59121. | 7825. | 14835. | 18490. | 29381. | 47939. | 111877. | 175062. | 190567. | 192100. | 192100. | 192100. | 192100. |
| Belton | 210638. | 176758. | 0. | 0. | 0. | 0. | 125. | 40274. | 115098. | 195270. | 259946. | 417350. | 457600. | 457600. |
| George | 17847. | 15589. | 0. | 0. | 0. | 0. | 0. | 207. | 10591. | 17309. | 25752. | 36964. | 37100. | 37100. |
| Grang | 39664. | 28001. | 0. | 0. | 0. | 0. | 5. | 10193. | 26925. | 58372. | 65097. | 65500. | 65500. | 65500. |
| Total | 1162319. | 521329. | 260551. | 269271. | 283339. | 407852. | 474224. | 755466. | 1050418. | 1140584. | 1384675. | 1609613. | 1932004. | 1949640. |

## Storage-Frequency Relationships for Granger Reservoir for Initial Storage Volume of 16,375 acre-feet (25% of Capacity) at the Beginning of April (Table 8.12 Reference Manual Page 290)

| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Month** | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
| **Mean** | 24,802 | 34,111 | 32,147 | 26,218 | 17,158 | 17,107 | 21,306 | 25,140 | 30,292 | 33,911 | 37,450 | 39,664 |
| **St Dev** | 16,663 | 23,434 | 26,662 | 26,600 | 22,817 | 21,980 | 23,775 | 25,360 | 26,366 | 26,651 | 26,855 | 28,001 |
| **Min** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **99%** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **98%** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **95%** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **90%** | 5,483 | 4,933 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.64 |
| **80%** | 14,351 | 11,064 | 6,070 | 0 | 0 | 0 | 0 | 0 | 0 | 2,407 | 2,072 | 3,823 |
| **70%** | 15,946 | 17,623 | 10,630 | 4,003 | 0 | 0 | 0 | 3,020 | 8,284 | 13,483 | 18,284 | 16,686 |
| **60%** | 17,754 | 20,658 | 15,623 | 7,110 | 0 | 1,720 | 2,998 | 8,273 | 18,128 | 20,873 | 26,619 | 26,925 |
| **50%** | 22,085 | 32,593 | 20,741 | 14,565 | 3,584 | 5,175 | 13,362 | 17,887 | 25,128 | 28,144 | 44,803 | 58,372 |
| **40%** | 24,165 | 42,172 | 47,452 | 34,051 | 12,650 | 14,710 | 22,365 | 27,197 | 37,623 | 45,860 | 55,496 | 65,097 |
| **30%** | 28,897 | 51,129 | 65,500 | 48,319 | 22,183 | 23,429 | 34,287 | 41,395 | 53,863 | 65,420 | 65,500 | 65,500 |
| **20%** | 65,500 | 65,500 | 65,500 | 65,500 | 42,262 | 23,429 | 45,783 | 61,120 | 65,500 | 65,500 | 65,500 | 65,500 |
| **10%** | 65,500 | 65,500 | 65,500 | 65,500 | 60,269 | 58,370 | 65,217 | 65,500 | 65,500 | 65,500 | 65,500 | 65,500 |
| **Max** | 65,500 | 65,500 | 65,500 | 65,500 | 65,500 | 65,500 | 65,500 | 65,500 | 65,500 | 65,500 | 65,500 | 65,500 |

## Conditional Reliability Modeling (CRM) Procedures

- Defining simulation sequences and performing simulations for each sequence in *SIM*. Add CR record to SIM DAT file.

- Assigning probabilities to each sequence and performing frequency and reliability analyses with *TABLES*. Add 5CRM record to TABLES TIN File for equal-weight option. Probability array options are controlled by 5CR1 and 5CR2 records as discussed in module 2.

## Modules for WRAP Online Course on Short-Term Conditional Reliability Modeling

Module 1 - Basics of Conditional Reliability Modeling (CRM)
[SIM CR Input Record and TABLES 5CRM Record]

Module 2 - Probability and Correlation Methods
[TABLES 5CR1, 5CR2, and 5COR Records]

## Brazos WAM Case Study CRM Application

R. Wurbs, S. Schnier, H. Olmos, “Short-Term Reservoir Storage Frequency Relationships,” *Journal of Water Resources Planning and Management*, ASCE, 138:597-605, November 2012.

(Available at WRAP website: https://wrap.engr.tamu.edu/

R. Wurbs, R. Hoffpauir, S. Schnier, Application of Expanded WRAP Modeling Capabilities to the Brazos WAM, TR-389, Second Edition, Texas Water Resources Institute, August 2011.

## Short-Term Conditional Reliability Modeling

## Module 2 – Probability and Correlation Methods

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Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the
Texas Commission on Environmental Quality

June 2021

## Modules for WRAP Online Course on Short-Term Conditional Reliability Modeling

1. Basics of Conditional Reliability Modeling (CRM)
   [SIM CR Input Record and TABLES 5CRM Record]
2. Probability and Correlation Methods
   [TABLES 5CR1, 5CR2, and 5COR Records]

## Documentation of Conditional Reliability Modeling (CRM) Features of WRAP

Reference Manual, Pages 265-342,
*Chapter 8 Short-Term Conditional Reliability Modeling*

Users Manual, Chapter 3 SIM Input Records, Page 54,
*CR Record – Conditional Reliability Modeling*

Users Manual, Chapter 5 Program TABLES, Pages 226-233,
*5CRM, 5CR1, 5CR2, and 5COR Records*

## Conditional Reliability Modeling (CRM)

### Short-Term Frequency and/or Reliability Analyses Conditioned on Preceding Reservoir Storage

1. The hydrologic period-of-analysis is divided within SIM into many shorter simulation sequences as specified by a CR record inserted in the DAT file. Simulations with the multiple hydrologic sequences are automatically repeated by SIM with each sequence beginning the same initial reservoir storage contents.
2. CRM is performed with SIM with the same input dataset as a conventional simulation, with the exception that a CR record is added to the DAT file. Results are recorded by SIM in an output file with filename extension CRM (rather than OUT) and the DSS file.
3. The majority of TABLES capabilities are applicable to either CRM or conventional simulations, but results are interpreted differently. CRM options are controlled with 5CRM, 5CR1, 5CR2, and 5COR records.

## CRM Procedures

- Defining simulation sequences and performing simulations for each sequence in *SIM*. [Module 1]
- Assigning probabilities to each sequence in TABLES [present Module 2]
- Performing frequency and reliability analyses with *TABLES* [Module 1].

## Alternative CRM Strategies for Assigning Probabilities to Simulation Sequences within TABLES

1. Equal-Weight (5CRM Record) [Module 1]
2. Probability Array (5CR1 and 5CR2 Records) [Module 2]
    - Flow-Frequency (FF) Array
    - Storage-Flow-Frequency (SFF) Array

## TABLES Reliability and Frequency Analyses Performed with 2REL, 2FRE, 2FRQ, and 2RES Records

- Tables of volume and period reliabilities are created with 2REL records for either the entire period-of-analysis or a specified month of the year.
- Tables of frequency metrics are created with 2FRE records for either the entire period-of-analysis or a specified month of the year using optionally the basic relative frequency formula [F = (n/N)100%], Weibull formula [F = (n/(N+1))100%], or the normal or log-normal probability distribution.
- TABLES input records and computations are the same with either CRM or conventional long-term simulation analysis, but the results are interpreted differently.

## Reliability and Frequency Metrics Conditioned on Preceding Reservoir Storage

Capabilities for supplying water use and hydropower targets, meeting instream flow targets, and refilling reservoir storage over the next several months depend upon:

1. the amount of water currently available in reservoir storage
2. hydrology that occurs over the future several-month period of interest as represented by naturalized stream flow and net reservoir evaporation-precipitation rates

## TABLES Equal-Weight and Probability Array Options for Assigning Probabilities to Simulation Sequences

Equal-Weight Option (5CRM Record in TIN File)

Frequency and reliability analyses are based simply on treating each simulation sequence as one possibility out of the total number of simulation sequences. [Module 1]

Probability Array Option (5CR1 and 5CR2 Records in TIN File)

An adopted set of options may be based on either a flow-frequency (FF) or storage-flow-frequency (SFF) relationship. A SFF relationship allows preceding storage content or changes in storage content to be considered in assigning probabilities to each of the individual sequences. [Module 2]

## FF and SFF Versions of Probability Array Strategy for Assigning Probabilities to Simulation Sequences Using Sets of Options on 5CR1 and 5CR2 Records

- The flow frequency (FF) relationship based methodology is based on assigning exceedance probabilities directly to naturalized flow volumes using either the log-normal probability distribution or Weibull formula. Preceding reservoir storage may be either ignored or incorporated using only sequences with preceding storage falling within a specified range.
- The storage-flow-frequency (SFF) relationship based methodology is based on probabilistically representing deviations in naturalized flow volumes from the amounts indicated by a regression relationship between naturalized stream flow volume and either preceding reservoir storage volume or change in preceding storage volume.

## TABLES 5CRM Record
## Used with Equal-Weight Option [Module 1]
(Users Manual Page 226)

CD – 5CRM record identifier

CRHEAD – option to not insert CRM header at the top of each table
(The header is inserted by default.)

The 5CRM and 5CR2 (equal-weight and probability array options, respectively) records instruct TABLES to open a SIM simulation results CRM output file rather than OUT output file.

## Probability Array Methods

1. Options selected on the 5CR1 record are employed by TABLES to develop a FF relationship between exceedance frequency and monthly naturalized flow volume Q or a SFF relationship between exceedance frequency and Q%.

2. Options selected on the **5CR2 record** are employed by TABLES to convert the FF or SFF array to an **incremental probability array** that assigns incremental probabilities to each CRM simulation sequence. The incremental probabilities for all simulation sequences sum to 1.0.

## Storage-Flow-Frequency (SFF) Methodology

The SFF method relates exceedance probabilities to the random variable Q% defined by Equation 8.8 on RM page 303.

$$Q\% = \left(\frac{Q}{Q_S}\right)(100\%)$$

where Q is the naturalized flow volume over one or more months and $Q_S$ is the corresponding expected value of the naturalized flow volume determined from a regression equation reflecting preceding storage volume or changes in storage volume over a specified number of preceding months.

$Q_S = a \times e^{S/b}$

## Regression Equations Relating Naturalized Flow Volume ($Q_S$) to Storage (S)

### (a, b, and c are regression coefficients)

$$Q_S = a\, e^{(S/b)}$$

$$Q_S = bS^C$$

$$Q_S = a + bS$$

$$Q_S = a + bS^C$$

## Exceedance Frequency and Incremental Probability Arrays

5CR1 Record - Options for computing exceedance probability relationships from flows and storage read by TABLES from a long-term SIM simulation output OUT file.

5CR2 Record - Options for computing incremental probabilities from CRM results read from SIM output CRM file and SFF or FF relationship developed with 5CR1 record.

TABLES frequency 2FRE and reliability 2REL routines employ an counting algorithm based on converting to 1,000,000 possibilities. $N_S$ denotes the number of sequences associated with each SIM sequence with incremental probability $P_S$.

$$N_S = 1{,}000{,}000\ P_S$$

## Example of Applying Probability Array in Reliability and Frequency Counts (Table 8.19 Page 311)

| Simulation Sequence | Incremental Probability | $N_S$ Count |
|---|---|---|
| | | |
| 1 | 0.019254 | 19,254 |
| 2 | 0.025347 | 25,347 |
| 3 | 0.007469 | 7,469 |
| 4-67 | not shown | |
| 73 | 0.011528 | 11,528 |
| 74 | 0.017862 | 17,862 |
| Totals | 1.000000 | 1,000,000 |

### 5CR1 Record – CRM Options for Developing a Flow Frequency (FF) or Storage Flow Frequency (SFF) Array

NFLOW – number of control points for naturalized flow
NSTOR – number of control points or reservoirs for reservoir storage
TCR2 – starting month for annual cycle option
blank for non-annual cycle option
FM – number of months for naturalized flow volume
CRS – total storage volume or change in storage volume
DIST – Weibull formula or log-normal distribution
FIT – regression options for storage-flow function
INTZERO – whether or not intercept is forced to zero
A, B, C – coefficients for regression equation
LOWLIM – lower storage limit for flow sequence selection
UPLIM – upper storage limit for flow sequence selection
FILE2 – options for recording results to SFF or TOU files

### 5CR2 Record – Options for Building Incremental Probability Array

NFLOW – number of control points for naturalized flow
NSTOR – number of control points or reservoirs for reservoir storage
READINI – starting initial reservoir storage contents volume
FM – number of months for naturalized flow volume
CSVO – preceding change in reservoir storage volume
FIT – regression options for storage-flow function
FILE1 – FF or SFF created with 5CR1 record or read from SFF file
FILE0 – whether SFF array is written to SFF file
CSV – preceding change in storage or total storage
MFACTOR – multiplier factor
A, B, C – coefficients for regression equation
QX – optional Q adjustment factor

## Statistical Correlation Analysis of Naturalized Stream Flow and Preceding Reservoir Storage

- The standard linear correlation coefficient (r) computed with Equation 8.17 on page 304 of Reference Manual provides a measure of the linear correlation between two variables.

$$-1.0 \leq r \leq 1.0$$

- The Spearman rank correlation coefficient ($r_r$) computed with Equation 8.18 on page 305 of the Reference Manual provides a measure of the linear correlation between the ranks of two variables.

$$-1.0 \leq r_r \leq 1.0$$

## 5COR Record – Correlation Coefficients

(Users Manual Pages 232-233)

NFLOW – number of control points for naturalized flow

NSTOR – number of control points or reservoirs for reservoir storage

TCR2 – starting month for annual cycle option
blank for non-annual cycle option

FM – number of months for naturalized flow volume

Control points and reservoirs for the flow-storage correlation analysis are listed on a second and third 5COR record.

## Correlation Coefficients for Alternative 5CR1 Record CRS Options

(Table 8.21, Reference Manual Page 315)

| 1<br>CRS | 2<br>Correlation Coefficient | 3<br>Spearman Coefficient | 4<br>Exponential Correlation | 5<br>Combined Eq. Correlation | 6<br>Number of Sequences |
|---|---|---|---|---|---|
| 1 month | 0.1106 | 0.2824 | 0.2175 | 0.2080 | 37 |
| 2 months | 0.2643 | 0.3269 | 0.3240 | 0.2955 | 43 |
| 3 months | 0.2089 | 0.3066 | 0.3143 | 0.2015 | 44 |
| 4 months | 0.3940 | 0.4459 | 0.4516 | 0.3171 | 44 |
| 5 months | 0.3287 | 0.4926 | 0.4482 | 0.3310 | 47 |
| 6 months | 0.3435 | 0.5391 | 0.4784 | 0.3519 | 52 |
| 7 months | 0.3364 | 0.5255 | 0.4757 | 0.3513 | 59 |
| 8 months | 0.4053 | 0.5884 | 0.5667 | 0.3882 | 66 |
| 9 months | 0.3903 | 0.5688 | 0.5371 | 0.3734 | 64 |
| 10 months | 0.4498 | 0.6154 | 0.5957 | 0.4456 | 52 |
| 11 months | 0.4399 | 0.6438 | 0.6067 | 0.4494 | 49 |
| 12 months | 0.3204 | 0.5476 | 0.5272 | 0.3242 | 51 |
| Total w Limits | 0.1081 | 0.3218 | 0.3703 | 0.1207 | 36 |
| Total w/o Lim | 0.3115 | 0.5999 | 0.6132 | 0.3001 | 74 |

## Brazos WAM Case Study CRM Application

R. Wurbs, S. Schnier, H. Olmos, "Short-Term Reservoir Storage Frequency Relationships," *Journal of Water Resources Planning and Management*, ASCE, 138:597-605, November 2012.

(Available at WRAP website: https://wrap.engr.tamu.edu/)

R. Wurbs, R. Hoffpauir, S. Schnier, Application of Expanded WRAP Modeling Capabilities to the Brazos WAM, TR-389, Second Edition, Texas Water Resources Institute, August 2011.

## Brazos WAM CRM Analyses
## Discussed in 2012 Journal Paper

- Paper focuses on comparing the equal-weight method versus the storage-flow-frequency (SFF) based probability array method.
- Five reservoirs in Little River Sub-basin. Proctor is operated as an individual reservoir. Belton, Stillhouse Hollow, Georgetown, and Granger Reservoirs operated as a four-reservoir system.
- 108-year hydrologic period-of-analysis of January 1900 through December 2007 divided into 107 annual cycle sequences starting on July 1 each year and alternatively into 1,285 twelve-month non-annual (monthly) cycle sequences.
- Four executions of SIM with initial reservoir storage contents set at 100%, 75%, 50%, and 25% of water supply storage capacity.

## Long-Term Simulation Frequency Statistics for End-of-June Storage (Table 3 of Journal Paper)

| Exceedance | End-of-June Storage as Percentage of Capacity of | | | | | |
|---|---|---|---|---|---|---|
| Frequency | Belton | Stillhouse | Georgetown | Granger | Total | Proctor |
| 100% | 80.03 | 76.39 | 0.00 | 70.85 | 82.35 | 0.00 |
| 98% | 82.61 | 83.43 | 26.31 | 86.54 | 83.02 | 9.19 |
| 95% | 87.11 | 86.59 | 53.62 | 88.40 | 85.20 | 28.48 |
| 90% | 92.17 | 92.04 | 62.30 | 94.87 | 89.62 | 45.98 |
| 80% | 98.28 | 98.27 | 84.35 | 97.70 | 96.47 | 70.87 |
| 70% | 99.58 | 100.0 | 96.32 | 100.0 | 99.06 | 91.57 |
| 60% | 100.0 | 100.0 | 99.77 | 100.0 | 99.91 | 95.49 |
| 50% | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 98.79 |
| 40% | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

## Storage-Frequency Relationship for Lake Proctor Based on Equal-Weight Method (Table 4 of Journal Paper)

| Exceedance Frequency | Beginning-of-July Storage as Percentage of Capacity | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 100 | 75 | 50 | 25 | 100 | 75 | 50 | 25 |
| | End-of-September Storage (% capacity) | | | | End-of-June Storage (% capacity) | | | |
| 100% | 78.32 | 56.27 | 35.63 | 13.59 | 58.10 | 39.76 | 22.03 | 3.25 |
| 98% | 79.73 | 56.97 | 36.09 | 13.86 | 62.74 | 41.46 | 23.27 | 3.95 |
| 95% | 81.12 | 58.11 | 36.84 | 14.32 | 68.11 | 43.23 | 24.52 | 4.68 |
| 90% | 82.68 | 59.11 | 37.49 | 14.73 | 70.59 | 46.35 | 26.60 | 5.70 |
| 80% | 83.96 | 60.11 | 38.12 | 15.10 | 78.22 | 48.98 | 28.23 | 6.60 |
| 70% | 84.86 | 60.78 | 38.55 | 15.37 | 94.55 | 49.47 | 28.69 | 6.89 |
| 60% | 85.00 | 61.35 | 38.91 | 15.61 | 96.11 | 59.31 | 28.88 | 7.01 |
| 50% | 85.05 | 61.41 | 38.97 | 15.64 | 99.51 | 80.69 | 35.22 | 7.12 |
| 40% | 88.17 | 61.49 | 39.02 | 15.67 | 100.0 | 96.08 | 87.71 | 30.50 |
| 30% | 90.43 | 61.54 | 39.05 | 15.69 | 100.0 | 100.0 | 99.06 | 76.38 |
| 20% | 93.29 | 62.77 | 39.45 | 15.93 | 100.0 | 100.0 | 100.0 | 100.0 |
| 10% | 100.0 | 64.92 | 40.54 | 16.59 | 100.0 | 100.0 | 100.0 | 100.0 |
| 0% | 100.0 | 100.0 | 42.52 | 17.86 | 100.0 | 100.0 | 100.0 | 100.0 |

## Storage-Frequency Relationship for 4-Reservoir System Based on Equal-Weight Method (Table 5 of Journal Paper)

| Exceedance Frequency | Beginning-of-July Storage as Percentage of Capacity | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 100 | 75 | 50 | 25 | 100 | 75 | 50 | 25 |
| | End-of-September Storage (% capacity) | | | | End-of-June Storage (% capacity) | | | |
| 100% | 89.74 | 65.83 | 47.93 | 18.70 | 82.35 | 59.10 | 36.14 | 13.88 |
| 98% | 90.32 | 67.29 | 48.30 | 18.88 | 86.83 | 63.72 | 39.95 | 16.57 |
| 95% | 91.07 | 67.94 | 48.89 | 19.23 | 89.60 | 65.85 | 42.83 | 20.26 |
| 90% | 92.03 | 68.75 | 49.53 | 19.54 | 94.87 | 75.03 | 52.08 | 28.77 |
| 80% | 92.42 | 69.05 | 49.98 | 19.94 | 97.77 | 87.29 | 64.99 | 41.95 |
| 70% | 93.93 | 70.57 | 51.39 | 21.14 | 99.05 | 93.60 | 72.54 | 51.34 |
| 60% | 94.68 | 71.22 | 52.34 | 22.11 | 99.89 | 97.99 | 83.19 | 60.71 |
| 50% | 95.94 | 74.27 | 55.64 | 24.87 | 100.0 | 99.51 | 93.69 | 80.56 |
| 40% | 97.32 | 76.63 | 58.22 | 27.07 | 100.0 | 100.0 | 99.81 | 94.24 |
| 30% | 98.07 | 80.36 | 62.61 | 31.11 | 100.0 | 100.0 | 100.0 | 99.89 |
| 20% | 99.35 | 88.31 | 71.37 | 38.38 | 100.0 | 100.0 | 100.0 | 100.0 |
| 10% | 99.83 | 95.77 | 82.81 | 48.53 | 100.0 | 100.0 | 100.0 | 100.0 |
| 0% | 100.0 | 98.60 | 88.03 | 63.98 | 100.0 | 100.0 | 100.0 | 100.0 |

## Correlation Coefficients for Beginning-of-July Storage Versus Available Flow (Table 6 of Journal Paper)

| Form of Relationship | Number of Months of Flow Volume 1 | 2 | 3 | 6 | 9 | 12 |
|---|---|---|---|---|---|---|
| **Correlation Coefficients (r) for Lake Proctor Storage versus Flow** | | | | | | |
| Linear | 0.113 | 0.121 | 0.155 | 0.169 | 0.145 | 0.112 |
| Spearman | 0.440 | 0.426 | 0.415 | 0.289 | 0.251 | 0.106 |
| Exponential | 0.400 | 0.384 | 0.368 | 0.139 | 0.229 | 0.105 |
| **Correlation Coefficients (r) for 4-Reservoir System Storage versus Flow** | | | | | | |
| Linear | 0.182 | 0.168 | 0.181 | 0.211 | 0.167 | 0.112 |
| Spearman | 0.612 | 0.585 | 0.568 | 0.336 | 0.225 | 0.120 |
| Exponential | 0.540 | 0.574 | 0.569 | 0.312 | 0.349 | 0.118 |

## Storage-Frequency Relationship for Lake Proctor Based on Probability Array Method (Table 7 of Journal Paper)

| Exceedance | Beginning-of-July Storage as Percentage of Capacity | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Frequency | 100 | 75 | 50 | 25 | 100 | 75 | 50 | 25 |
| | End-of-September Storage (% capacity) | | | | End-of-June Storage (% capacity) | | | |
| 100% | 78.32 | 56.27 | 35.63 | 13.59 | 58.10 | 39.76 | 22.03 | 3.25 |
| 98% | 80.59 | 56.34 | 36.09 | 13.60 | 62.28 | 41.76 | 24.21 | 4.38 |
| 95% | 81.17 | 58.00 | 36.77 | 13.92 | 67.40 | 43.12 | 24.21 | 4.38 |
| 90% | 82.69 | 59.14 | 37.08 | 14.29 | 70.88 | 46.17 | 26.51 | 4.71 |
| 80% | 83.97 | 59.64 | 37.83 | 14.93 | 82.45 | 48.97 | 28.33 | 6.77 |
| 70% | 84.97 | 60.69 | 37.83 | 14.93 | 94.70 | 49.47 | 28.82 | 6.96 |
| 60% | 85.05 | 61.35 | 38.39 | 14.93 | 96.19 | 53.47 | 29.17 | 6.99 |
| 50% | 87.62 | 61.43 | 38.93 | 15.13 | 98.79 | 71.70 | 31.62 | 7.01 |
| 40% | 90.13 | 61.50 | 39.00 | 15.61 | 100.0 | 94.53 | 42.47 | 8.61 |
| 30% | 93.43 | 61.53 | 39.03 | 15.68 | 100.0 | 98.75 | 63.86 | 8.61 |
| 20% | 100.0 | 61.96 | 39.05 | 15.69 | 100.0 | 100.0 | 98.79 | 8.61 |
| 10% | 100.0 | 63.63 | 40.10 | 15.69 | 100.0 | 100.0 | 100.0 | 72.57 |
| 0% | 100.0 | 100.0 | 42.52 | 17.86 | 100.0 | 100.0 | 100.0 | 100.0 |

## Storage-Frequency for 4-Reservoir System Based on Probability Array Method (Table 8 of Journal Paper)

| Exceed | Beginning-of-July Storage as Percentage of Capacity | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Frequency | 100 | 75 | 50 | 25 | 100 | 75 | 50 | 25 |
| | End-of-September Storage (% capacity) | | | | End-of-June Storage (% capacity) | | | |
| 100% | 89.74 | 65.83 | 47.93 | 18.70 | 82.35 | 59.10 | 36.14 | 13.88 |
| 98% | 90.69 | 65.89 | 47.93 | 18.70 | 86.79 | 63.51 | 39.68 | 16.34 |
| 95% | 91.25 | 66.08 | 48.09 | 18.78 | 90.41 | 65.37 | 42.22 | 19.02 |
| 90% | 92.37 | 66.65 | 48.57 | 19.02 | 95.05 | 73.03 | 50.36 | 27.36 |
| 80% | 93.60 | 67.16 | 48.79 | 19.43 | 98.34 | 83.79 | 60.53 | 37.63 |
| 70% | 93.98 | 67.80 | 49.57 | 19.56 | 99.44 | 89.65 | 68.04 | 45.27 |
| 60% | 95.69 | 68.02 | 49.70 | 19.61 | 100.0 | 96.43 | 81.26 | 60.32 |
| 50% | 97.17 | 68.04 | 49.72 | 19.62 | 100.0 | 98.65 | 84.68 | 62.30 |
| 40% | 97.95 | 69.19 | 50.86 | 20.64 | 100.0 | 99.97 | 94.03 | 81.22 |
| 30% | 98.92 | 71.17 | 53.39 | 22.66 | 100.0 | 100.0 | 100.0 | 98.57 |
| 20% | 99.90 | 76.00 | 58.79 | 27.67 | 100.0 | 100.0 | 100.0 | 100.0 |
| 10% | 100.0 | 87.68 | 63.63 | 39.40 | 100.0 | 100.0 | 100.0 | 100.0 |
| 0% | 100.0 | 98.60 | 88.03 | 63.98 | 100.0 | 100.0 | 100.0 | 100.0 |

## Comparative Summary of CRM Options

(Reference Manual Pages 334-342)

1. Equal-Weight Strategy versus Probability Array Strategy
2. Define Annual or Non-Annual (Monthly) Cycles (SIM CR Record)
3. Adopt Probability Array Options (TABLES 5CR1 and 5CR2 Records)
   - Flow-Frequency (FF) Relationship Options
     * Selection of control points and months for naturalized flows
     * Upper and lower limits defining reservoir storage range
     * Choice of log-normal or Weibull probability
   - Storage-Flow-Frequency (SFF) Relationship Options
     * Selection of control points for storage and naturalized flow
     * Selection of months for naturalized stream flow volume
     * Choice of number of months for defining storage change
     * Upper and lower limits defining reservoir storage range
     * Choice of regression equation
     * Choice of log-normal or Weibull probability

## Water Rights Analysis Package (WRAP) Daily Modeling System

## Module 1 – Introductory Overview of Daily Features

Presented by Ralph Wurbs, Ph.D., P.E.
Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the

Texas Commission on Environmental Quality

May 2021

## This course on the WRAP Daily Modeling System consists of five modules.

1. **Introductory Overview of Daily Features (this module)**
2. Conversion of Monthly Datasets to Daily
3. Routing and Forecasting
4. Flood Control Reservoir Operations
5. SB3 Environmental Flow Standards

## Daily SIMD Modeling Features Not Included in the Monthly SIM Simulation

- Naturalized flow disaggregation
- Demand target disaggregation
- Routing of flow depletions and increases
- Forecasting stream flow availability
- Flood control reservoir operations
- Environmental flow standards that include high pulse flow components

## Evolution of WRAP Daily Modeling System

- Richard J. Hoffpauir, December 2010. *Daily Time Step Simulation with a Priority Order Based Surface Water Allocation Model*. Ph.D. Dissertation, Texas A&M University.
- Wurbs and Hoffpauir, May 2013. *Environmental Flows in Water Availability Modeling*, Texas Commission on Environmental Quality (TCEQ) Contract 582-12-10220, TWRI TR-440, 281 pages.
- Wurbs and Hoffpauir, May 2019. *WRAP Daily Modeling System*, TCEQ Contract 582-18-80410, TWRI TR-430, 3rd Edition, 342 pages.
- Wurbs and Hoffpauir, January 2021. *WRAP Daily Modeling System*, TCEQ Contract 582-21-10039, TWRI TR-430, 4th Edition, 345 pages.

## Illustrative Examples of Daily Modeling and Analysis Capabilities Found in the WRAP Manuals

- The example in the Fundamentals Manual is expanded in the following chapters of the Daily Manual.

  Chapter 7 Daily Version of Fundamentals Manual WAM
  Chapter 8 Environmental Flow Standard Examples

- Reference Manual Chapters 5 and 6 dealing with analyses of time series data from simulation input and output datasets are relevant to both daily and monthly data. The following daily manual chapter with six examples covers additional capabilities relevant primarily to the daily modeling system.

  Chapter 9 Frequency Analyses of Annual Series from a Daily Simulation

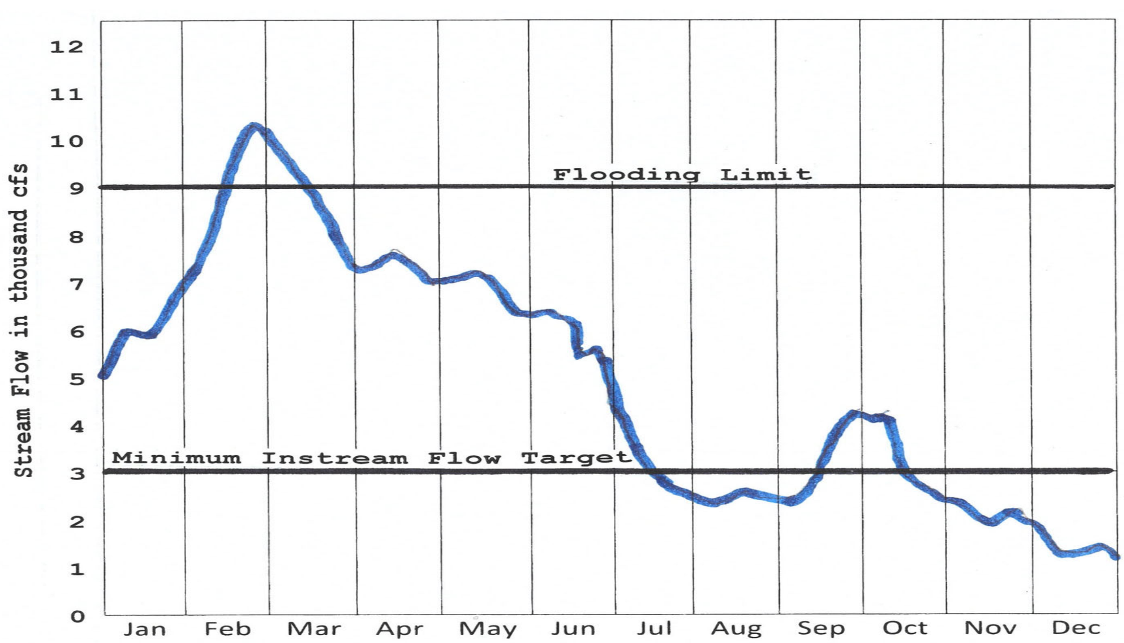
## Developmental Brazos, Trinity, and Neches Daily WAMs

- Wurbs, May 2019. *Daily Water Availability Model for the Brazos River Basin and San Jacinto-Brazos Coastal Basin*. TCEQ Contract 582-18-80410, TWRI TR-513, 238 pages.
- Wurbs, December 2019. *Daily Water Availability Model for the Trinity River Basin*. TCEQ Contract 582-18-80410, 193 pages.
- Wurbs, June 2020. *Daily Water Availability Model for the Neches River Basin*. TCEQ Contract 582-18-80410, 199 pages.

## Strategies for Applying the Daily Modeling System

- Computation of daily instream flow targets for SB3 environmental flow standards (EFS) in a daily SIMD simulation that are summed to monthly volumes for incorporation as target series TS records in a monthly SIM input dataset.
- Performing SIMD simulation studies to support design or refinement of SB3 EFS or to evaluate capabilities for satisfying SB3 EFS working directly with daily simulation results.
- Performing daily simulation studies to analyze flood control reservoir operations and interactions between flood control, water supply, hydropower, and SB3 EFS.

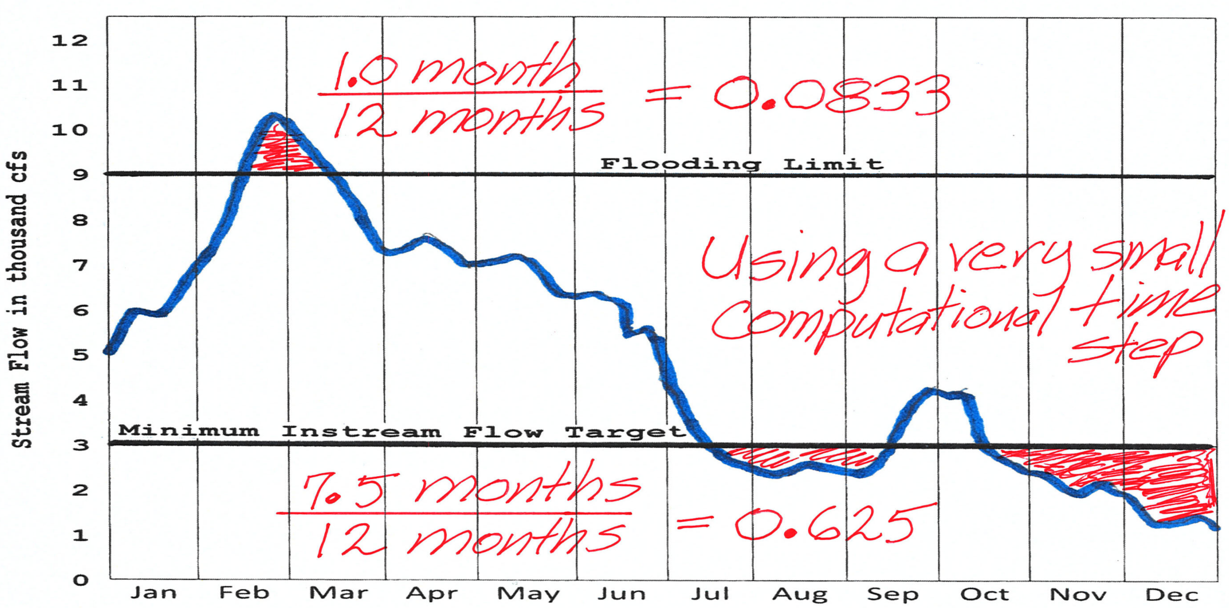
## Relevance of Computational Time Step



## Comparison of Frequencies Computed with Alternative Computational Time Steps

- With a small computational time step of an hour or less:
  The minimum instream flow is met 62.5% of the time.
  The flooding limit is exceeded 8.33% of the time.
- With a computational time step of one month:
  The minimum instream flow is met 75.0% of the time.
  The flooding limit is exceeded 0.00% of the time.

## Relevance of Computational Time Step



## Internet Sites

https://wrap.engr.tamu.edu/
WRAP software, manuals, and other materials

https://www.hec.usace.army.mil/
USACE Hydrologic Engineering Center HEC-DSSVue

https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/wam.html
WAM information including WRAP datasets for Texas river basins

http://twri.tamu.edu/
Texas Water Resources Institute (TWRI) technical reports

## WRAP Computer Programs

WinWRAP – Windows interface

- **Pre-Simulation Data Compilation**
  HYD – hydrology data for SIM
  **DAY and DAYH – routing parameters for SIMD**
  **HEC-DSSVue – time series data management**
- **River/Reservoir/Use System Simulation**
  SIM – monthly simulation model
  **SIMD – daily simulation model**
  SALT – salinity tracking
- **Post-Simulation Organization of Results**
  **TABLES – frequency, reliability, summaries**
  **HEC-DSSVue – data management, plots, mathematical operations, statistical analyses**

## U.S. Army Corps of Engineers (USACE)
## Hydrologic Engineering Center (HEC)
## Data Storage System (DSS) and HEC-DSSVue

https://www.hec.usace.army.mil/

- DSS and HEC-DSSVue are fully integrated in WRAP programs and manuals for managing time series data.
- WRAP Users Manual Chapter 6 HEC-DSS Data Storage System and HEC-DSSVue.
- HEC-DSSVue software and user's manual are available at the USACE HEC website.

## WRAP Manuals

*Water Rights Analysis Package (WRAP) Modeling System Reference Manual*, TWRI TR-255, 13th Edition, Jan 2021.

*Water Rights Analysis Package (WRAP) Modeling System Users Manual*, TWRI TR-256, 13th Edition, Jan 2021.

*Fundamentals of Water Availability Modeling with WRAP*, TWRI TR-283, 9th Edition, May 2019.

*WRAP Daily Modeling System*, TWRI TR-430, 4th Edition, January 2021.

*WRAP River System Hydrology*, TWRI TR-431, 3rd Edition, May 2019.

*Salinity Features of WRAP*, TWRI TR-317, July 2009.

## WRAP Daily Modeling System, TWRI TR-430, 4th Edition, January 2021.



## Daily Simulation Model SIMD Input Records

- Input records applicable to both monthly SIM and daily SIMD simulations and those additional records applicable only to daily SIMD are explained in Chapters 3 and 4, respectively, of the Users Manual.
- All 63 types of required and optional input records that can be used in a monthly SIM simulation are also applicable in the daily SIMD.
- 14 other types of input records are applicable only in a daily SIMD simulation (DC,DF,DO,DW,FF,FQ,FR,FC,JT,JU,PF,PO,RT,SC). The JT record is the only additional daily-only input record required for a daily SIMD simulation. The other 13 daily input records are optional.
- A monthly SIM simulation can be performed with a daily SIMD input dataset. SIM simply does not use the daily input records.
- A monthly simulation can be performed with SIMD for a SIM input dataset with no daily records. However, with one or more daily records in an input DAT file, SIMD can perform only daily simulations.

## SIMD Input Records (Users Manual Chapter 4 SIMD)

- DAT File Input Records

  General specifications: JT and JU records
  Flood control: FR, FF, FV, and FQ records
  Pulse flow components of instream flow targets: PF and PO
  Control point identifiers for DF records in DSS file: DF

- Records in Either DAT or DIF Input Files

  Target and forecast options for individual rights: DW and DO

- DIF File Input Records

  Routing and disaggregation specifications: RT and DC

- Hydrology DSS Input File Records

  Daily stream flows: DF records

## Water Availability Modeling Process

***Natural Hydrology***

Period-of-analysis monthly naturalized flows at primary control points are included in the SIM/SIMD input dataset and are distributed to secondary control points within the simulation. **SIMD also includes disaggregation of monthly naturalized flows to daily.** Reservoir net evaporation-precipitation rate sequences and other hydrology-related data are also included in the simulation input.

***Specified Water Development, Management, and Use Scenario***

SIM and SIMD simulate a scenario of water allocation, management, and use during an assumed repetition of historical natural hydrology. **SIMD includes flood control reservoir operations and detailed modeling of SB3 EFS.**

***Organization, Display, and Analyses of Simulation Results***

Simulation results are organized as metrics of supply reliability and flow and storage frequency and other measures of water availability.

## Natural Hydrology

- Naturalized flows at primary (known-flow) control points (IN records)
- **Daily pattern hydrographs used to disaggregate monthly naturalized flows to daily (DF records)**
- Flow distribution to secondary control points (FD and WP records in DIS file)
- Channel loss factors (CP records)
- Net reservoir surface evaporation less precipitation depths (EV records)

## Water Development, Allocation, Management, and Use

(WR,IF,ES,HC,WS,OR,UC,HP,SO,UP,RF,DI,EA,ML,MS,BU,FS, CV,TS,PX records and daily DC,PF,PO,DW,FR,FF,FQ records)

- Water right priority systems
- Water supply diversion target options
- Return flow specifications
- **Instream flow requirements**
- Hydroelectric energy generation
- Reservoirs and their operation
- Multiple-reservoir/river system operations
- Multiple owner reservoirs
- Off-channel storage
- Conveyance facilities
- **Reservoir flood control operations**

## Water Availability Indices Developed with TABLES

- Volume reliability
- Period reliability for **daily**, monthly, or annual target or specified percentage of target
- Exceedance frequencies for reservoir storage, regulated flows, unappropriated flows, and other variables, **including annual series of x-day minima or maxima**.
- Summary tables, water budgets, and other metrics

## SIMD Simulation Results SUB and DSS Files

- Simulation results for monthly OUT, daily SUB, and monthly and daily DSS output files for control points, water rights, and/or reservoirs selected by JD, CO, WO, GO, and RO records.
- Any of the 43 simulation results variables listed on page 47 of Users Manual can be selected for inclusion in the DSS file using the OF record. OUT and SUB files include all variables.
- The SUB file is the daily equivalent of the monthly OUT file. The SUB file in text format read by TABLES is activated by input switch SUBFILE in JT record field 11.
- DSS file in format read by HEC-DSSVue or TABLES is activated by DSS(3) on OF record (Users Manual page 45). A single DSS file contains both daily and monthly simulation results.

## DSS, HEC-DSSVue, and TABLES

- The Data Storage System (DSS) developed by the USACE Hydrologic Engineering Center (HEC) is fully integrated in the WRAP programs. The DSS interface HEC-DSSVue is an integral component of WRAP.
- WRAP program TABLES input records are explained in Chapter 5 of the Users Manual. Daily (type 6) record tables or tabulations are developed from data from a SIMD simulation SUB or DSS output file or any other DSS file. Daily TABLES input records include daily versions of all monthly (type 2) input records and 6REL, 6FRE, 6FRQ, and 6RES records.
- Frequency analyses of annual series as well as daily series are performed with daily data using relative frequency or probability distribution function options. Examples of annual series include the minimum or maximum daily or multiple-day (such as 7-day low flows) of stream flows, reservoir storage volumes, or any other variables.
- Daily SIMD simulation results also include aggregated monthly quantities for all simulation result variables.

## WRAP Programs HYD, DAY, and DAYH

- Program HYD documented by the Hydrology Manual consists of a set of routines for compiling and updating monthly SIM hydrology input data. HYD has no features for daily data.
- Program DAY described in Appendix A of the Daily Manual is primarily designed for calibration of lag and attenuation routing parameters based on statistical analysis of stream flow changes. Other daily flow compilation and statistical analysis routines are also included in DAY.
- Program DAYH described in Appendix B of the Daily Manual calibrates routing parameters for the lag and attenuation routing method and Muskingum routing method using a genetic search optimization algorithm.

## Water Rights Analysis Package (WRAP)
## Daily Modeling System

## Module 2 – Conversion of Monthly Datasets to Daily

Presented by Ralph Wurbs, Ph.D., P.E.
Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the

Texas Commission on Environmental Quality

May 2021

## WRAP Daily Modeling System Course Modules

1. Introductory Overview of Daily Features
2. **Conversion of Monthly Datasets to Daily** (this module)
3. Routing and Forecasting
4. Flood Control Reservoir Operations
5. SB3 Environmental Flow Standards

**WRAP Daily Modeling System, TWRI TR-430, 4th Edition, January 2021.**

Chapter 1 WRAP Modeling System
**Chapter 2 Daily Modeling System**
Chapter 3 Flow Routing and Forecasting
Chapter 4 Routing Parameter Calibration
Chapter 5 Reservoir Operations During Floods
Chapter 6 Environmental Flow Standards
**Chapter 7 Daily Version of Fundamentals Manual WAM**
Chapter 8 Environmental Flow Standard Examples
Chapter 9 Frequency Analyses of Annual Series
**Chapter 10 General Overview Summary**
References
Appendix A Program DAY
Appendix B Program DAYH

**WRAP Users, TWRI TR-256, 13th Edition, January 2021.**

Chapter 1 WRAP Modeling System
Chapter 2 WRAP-SIM Files
Chapter 3 WRAP-SIM Input Records
Chapter 4 SIMD Daily Simulation Model
Chapter 5 Program TABLES
Chapter 6 HEC-DSS Data Storage System and HEC-DSSVue

## SIMD Input Records (Users Manual Chapter 4 SIMD)

- DAT File Input Records
  - General specifications: JT and JU records
  - Flood control: FR, FF, FV, and FQ records
  - Pulse flow components of instream flow targets: PF and PO
  - Control point identifiers for DF records in DSS file: DF
- Records in Either DAT or DIF Input Files
  - Target and forecast options for individual rights: DW and DO
- DIF File Input Records
  - Routing and disaggregation specifications: RT and DC
- Hydrology DSS Input File Records
  - Daily stream flows: DF records

## **JT Record Parameters** (Users Manual Pages 139-142)

BEGYR, BEGMON, ENDYR, ENDMON specifies sub-period included in SUB file.

AFF creates flood frequency file.

DCSMM, RFASMM, ARPDSMM, RTGSMM creates optional tables in the daily SIMD message SMM file.

SUBFILE activates the SUB file.

SUBLIMIT overrides the default size limit on the SUB file.

DCFS allows input parameters on ES, PF, FF, FR, and FQ records that are by default input in cfs to be input in acre-feet/day rather than cfs.

## **JU Record Parameters** (Users Manual Pages 143-145)

DFMETH - Monthly to daily flow distribution option. (Default flow pattern defined by DF record daily flows.)

DFFILE – Input file for DF record daily flows. (Default is DSS file.)

WRMETH – Final flow changes are placed at (1) the beginning versus (2) within the water right priority sequence. (Default is beginning.)

WRFCST – Forecast flow changes are placed at (1) beginning versus (2) within the water right priority sequence. (Default is beginning.)

NORT – option to specify no routing even if DIF file contains RT records. (Default is that routing is activated by RT records in DIF file.)

DND and DSHORT – Option to supply target during first DND days of month. (Default is uniform distribution of monthly target over all days.)

DHMETHOD – Uniform disaggregation of HI record hydrologic indices. (Default is no disaggregation.)

DFMULT – Multiplier for DF record flows. (Default = 1.0)

VRL – Factor in DFMETH option 3 adjustment equation. (Default = 0.1)

## **Daily WRAP Modeling System**
(Daily Manual Table 10.1)

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 *SIMD* Simulation Results with *TABLES* and *HEC-DSSVue*

Calibration of Routing Parameters Using *DAY* or *DAYH*

## Comparative Summary of Modeling and Analysis Options

*Chapter 10 General Overview Summary*, WRAP Daily Modeling System, Wurbs and Hoffpauir, TWRI TR-430, 4th Ed., January 2021.

*Daily Water Availability Model for the Brazos River Basin and San Jacinto-Brazos Coastal Basin*. Wurbs, TCEQ Contract 582-18-80410, TWRI TR-513, 238 pages, May 2019.

*Daily Water Availability Model for the Trinity River Basin*. Wurbs, TCEQ Contract 582-18-80410, 193 pages, December 2019.

*Daily Water Availability Model for the Neches River Basin*. Wurbs, TCEQ Contract 582-18-80410, 199 pages, June 2020.

## Daily Manual 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 calibration | DAY statistical method | DAYH optimization options |
| negative incremental naturalized 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 | JU and DW record DND or ND |
| other right options | use only monthly options | DW and DO record options |

## Disaggregation of Simulation Variables from Monthly to Daily

- Net monthly evaporation-precipitation depths are uniformly distributed over the days of each month.
- Monthly WR record diversion and hydropower targets are by default uniformly distributed to daily.
- Daily water right DW and daily options DO record options (Users Manual Chapter 4, pages 147-151)
- DND and DSHORT options on JU record (page 143) and ND(wr), SHORT(wr), and NDSBU(wr) on DW record (Users Manual page 147).
- The remainder of this presentation will focus on disaggregation of monthly naturalized flows to daily.

## Disaggregating Monthly Naturalized Flows to Daily
JU Record DFMETH and DC Record DFMETHOD Options
(Users Manual Pages 143 and 166)

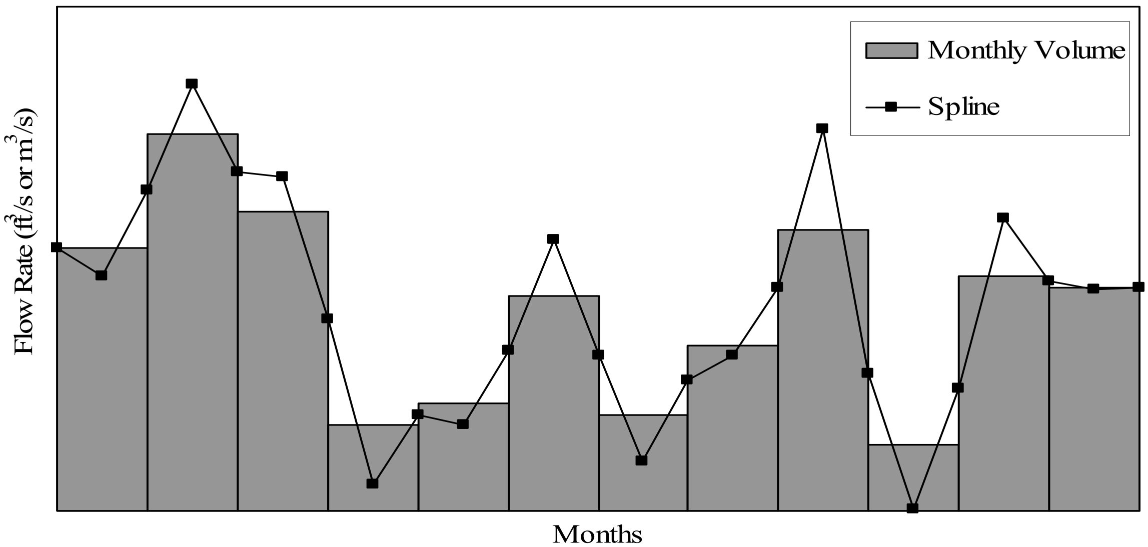
1. Uniform distribution
2. Linear interpolation
3. Variability adjustment
4. Daily flow pattern option with automatic repetition (recommended default standard option)

Options for transferring pattern hydrographs from one control point to another.

No disaggregation. Daily flows are employed directly without monthly flows.

## Daily Linear Interpolation of Monthly Flow Volumes

(Figure 2.2 on Page 23 of Daily Manual)




## Default DFMETH Option 4 Pattern Hydrographs

## Options for Storing DF Record Daily Flows

(JU Record DFFILE Options, Users Manual Page 143)

1. Daily flows on DF records are read from hydrology DSS file (recommended default standard option).
2. Daily flows on DF records are read from DIF file.
3. Daily flows on DF records are read from DIF file and recorded in DSS file without performing simulation.

## Daily Brazos, Trinity, and Neches WAMs

*Daily Water Availability Model for the Brazos River Basin and San Jacinto-Brazos Coastal Basin*. Wurbs, TCEQ Contract 582-18-80410, TWRI TR-513, 238 pages, May 2019.

*Daily Water Availability Model for the Trinity River Basin*. Wurbs, TCEQ Contract 582-18-80410, 193 pages, December 2019.

*Daily Water Availability Model for the Neches River Basin*. Wurbs, TCEQ Contract 582-18-80410, 199 pages, June 2020.

## Sources for Daily Flow Pattern Hydrographs in Developmental Daily Brazos, Trinity, and Neches WAMs

- Daily observed flows at USGS gages
- Naturalized daily flows
- Unregulated flows from USACE FWD model
- Daily flows from Soil and Water Analysis Tool (SWAT) watershed rainfall-runoff model were developed and investigated for comparison but not finally adopted.

## Number of Control Points

| Daily WAM | Total Number | Monthly IN Records | Daily Flows DF Records |
|---|---|---|---|
| Brazos | 3,152 | 77 | 58 |
| Trinity | 1,352 | 40 | 49 |
| Neches | 306 | 20 | 17 |

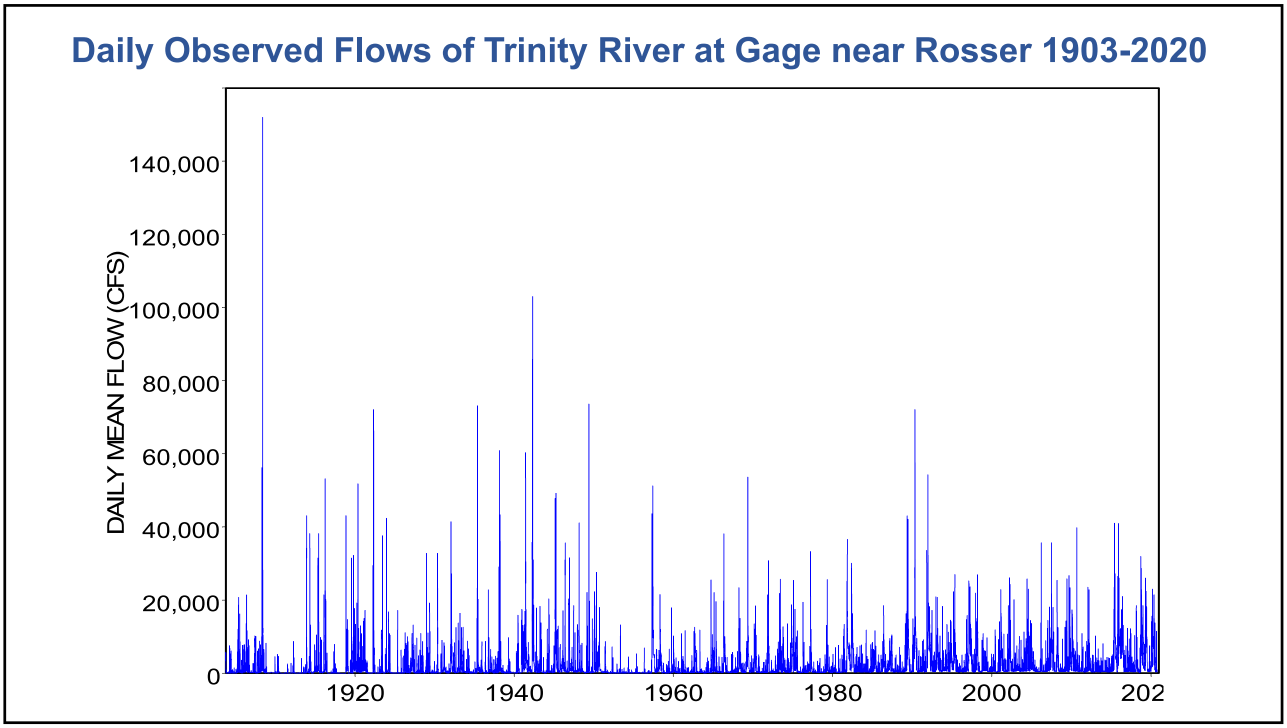
## Repetition of Daily Flow Pattern Hydrographs at Multiple Control Points

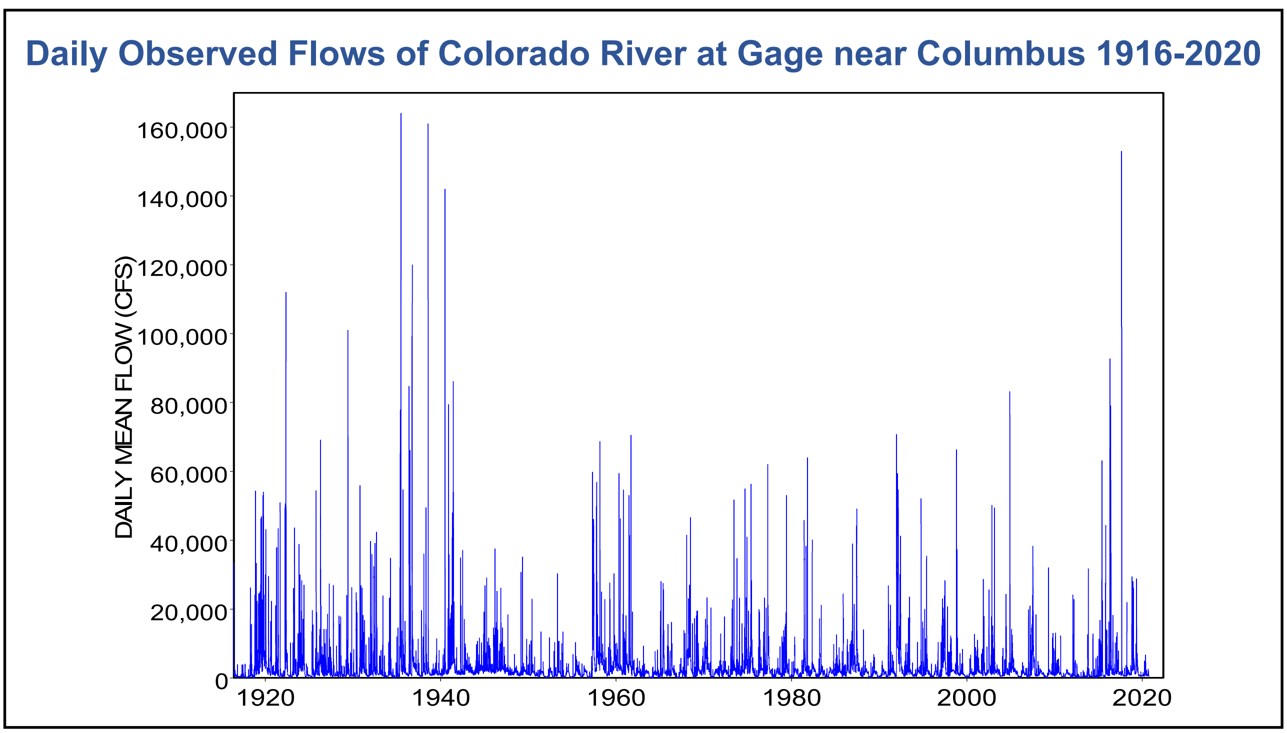
SIMD DAT File

```
JD    80    1940   1   1                           7                         13
JO     6
JT     0    0    0    0    0    0    0    0    0    1
JU     1
OF     0    0    2
DF           KIBR    NENE    NEAL    NEDI    NERO    MUJA   EFACU    ANAL    ANLU
DF           ATCH    AYSA    ANSR    NETB    NEEV    VIKO    PISL    NEBA
```

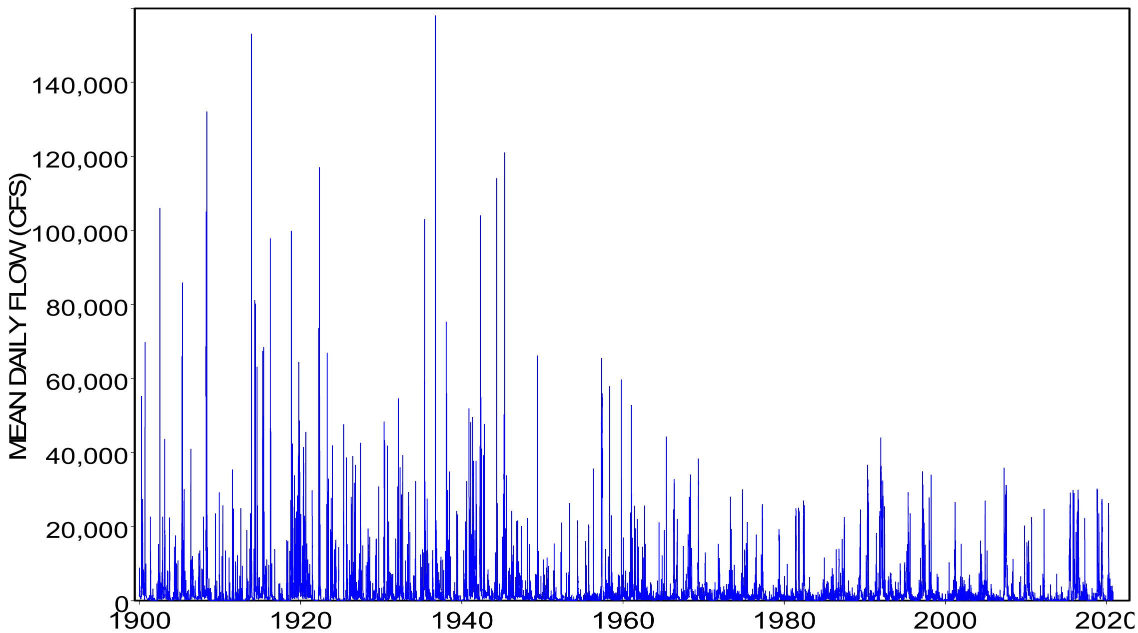
SIMD DIF File

```
DC  NESL   2   4    NEBA
```

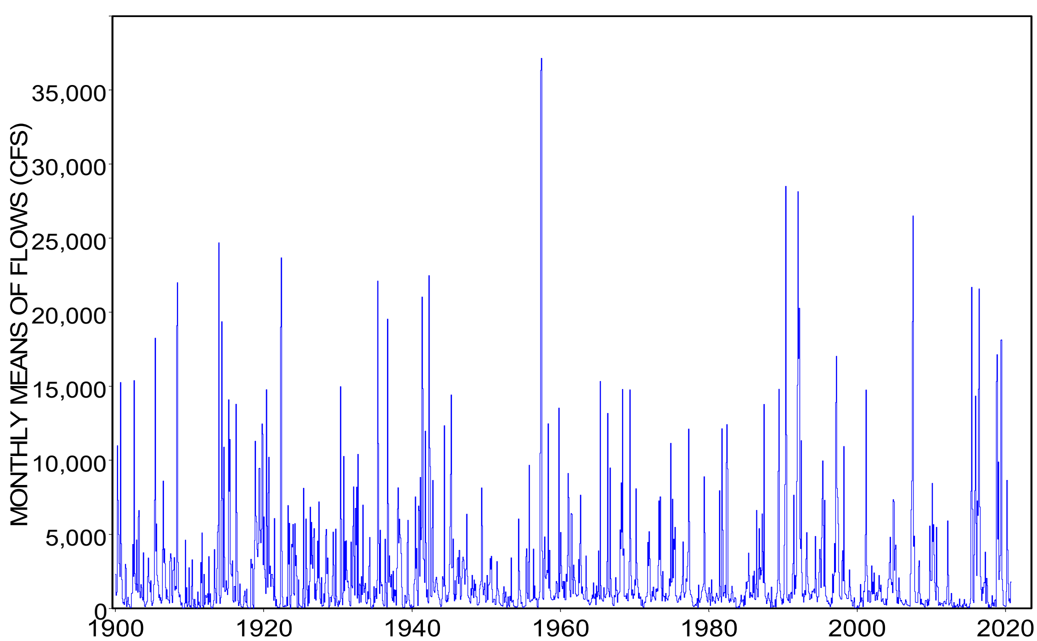

Daily Observed Flows of Trinity River at Gage near Rosser 1903-2020
DAILY MEAN FLOW (CFS)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1920
1940
1960
1980
2000
202


Daily Observed Flows of Colorado River at Gage near Columbus 1916-2020
DAILY MEAN FLOW (CFS)
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1920
1940
1960
1980
2000
2020

## Daily Observed Flows of Brazos River at Gage near Waco 1900-2020




## Monthly Observed Flows of Brazos River at Gage near Waco 1900-2020



## Frequency Metrics for Monthly and Daily Flows of Trinity River at Romayor

| | Monthly SIM Simulation | | | Daily SIMD Simulation | | |
|---|---|---|---|---|---|---|
| | Naturalized | Regulated | Unappropriated | Naturalized | Regulated | Unappropriated |
| | (cfs) | (cfs) | (cfs) | (cfs) | (cfs) | (cfs) |
| Mean | 9,129 | 5,986 | 4,361 | 9,114 | 6,204 | 4,790 |
| Standard Deviation | 11,162 | 8,692 | 8,710 | 14,100 | 11,826 | 11,748 |
| Minimum | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 99% | 0.00 | 141 | 0.00 | 0.00 | 0.00 | 0.00 |
| 98% | 78.5 | 415 | 0.00 | 53.3 | 0.00 | 0.00 |
| 95% | 275 | 730 | 0.00 | 225 | 0.00 | 0.00 |
| 90% | 585 | 1,026 | 0.00 | 479 | 0.00 | 0.00 |
| 85% | 922 | 1,132 | 0.00 | 723 | 504 | 0.00 |
| 80% | 1,391 | 1,196 | 0.00 | 1,017 | 834 | 0.00 |
| 75% | 1,831 | 1,370 | 0.00 | 1,336 | 1,016 | 0.00 |
| 70% | 2,283 | 1,513 | 0.00 | 1,688 | 1,127 | 0.00 |
| 60% | 3,337 | 1,897 | 0.00 | 2,506 | 1,434 | 0.00 |
| 50% | 4,734 | 2,288 | 0.00 | 3,712 | 1,891 | 0.00 |
| 40% | 7,158 | 2,668 | 662 | 5,638 | 2,383 | 0.00 |
| 30% | 10,593 | 4,742 | 3,060 | 8,826 | 3,727 | 1,692 |
| 25% | 12,264 | 6,994 | 4,730 | 11,052 | 5,658 | 3,532 |
| 20% | 15,349 | 9,295 | 7,935 | 13,908 | 8,323 | 6,211 |
| 15% | 19,038 | 12,570 | 10,880 | 17,770 | 11,856 | 10,026 |
| 10% | 23,251 | 15,782 | 14,720 | 23,871 | 17,339 | 15,568 |
| 5% | 31,122 | 23,746 | 22,376 | 35,660 | 28,263 | 26,930 |
| 2% | 44,629 | 35,241 | 33,309 | 53,662 | 45,412 | 44,172 |
| 1% | 55,634 | 45,082 | 43,400 | 69,862 | 60,139 | 58,838 |
| Maximum | 81,644 | 66,272 | 64,551 | 204,661 | 183,101 | 182,476 |

## Major Daily SIMD Simulation Capabilities

- Disaggregation of naturalized flows from monthly to daily.
- Routing (lagging and attenuating) streamflow depletions, return flows, and reservoir releases.
- Forecasting stream flow availability for WR record water rights and channel flow capacity for flood control reservoir FR record water rights.
- Simulation of reservoir flood control operations.
- Simulation of SB3 environmental flow standards including high pulse flow components.

## Water Rights Analysis Package (WRAP) Daily Modeling System

## Module 3 - Routing and Forecasting

Presented by Ralph Wurbs, Ph.D., P.E.
Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the

Texas Commission on Environmental Quality

May 2021

## WRAP Daily Modeling System Course Modules

1. Introductory Overview of Daily Features
2. Conversion of Monthly WAMs to Daily
3. **Routing and Forecasting** (this module)
4. Flood Control Reservoir Operations
5. SB3 Environmental Flow Standards

## WRAP Daily Modeling System, TWRI TR-430, 4th Edition, January 2021.



## Routing (Lagging and Attenuating) Daily Flow Changes

- Routing refers to the lag and attenuation of flow changes resulting from stream flow depletions (diversions and refilling storage), diversion return flows, and reservoir releases as the changes propagate downstream.
- Flow changes are propagated downstream in a monthly SIM simulation without lag and attenuation (without routing).
- Routing is optional in SIMD. Daily SIMD simulations may propagate flow changes downstream without routing. Optional features are available in SIMD for lagging and attenuating increases and decreases in stream flow caused by water rights as the effects of the water rights on stream flow move downstream. Routing is deactivated by NORT on JU record.

## Computational Tasks Repeated for Each WR and FR Record Water Right for Each Time Step

*Task 1A* – Amount of stream flow available to the WR record water right is the minimum of the CPFLOW array available flows at the control point of the water right and at relevant downstream control points. **Reverse routing is applied**.

*Task 1B* – For FR record flood control operations, determination of channel capacity based on allowable non-damaging limits at the control point of the FR record and relevant downstream control points. **Reverse routing is applied**.

*Task 2* – The water supply or hydropower target or flood release target is set.

*Task 3* – The water right is simulated. Decisions/actions regarding reservoir storage, water supply, hydropower, or flood control operations are made. Net evaporation volume is computed. Volume accounting is performed.

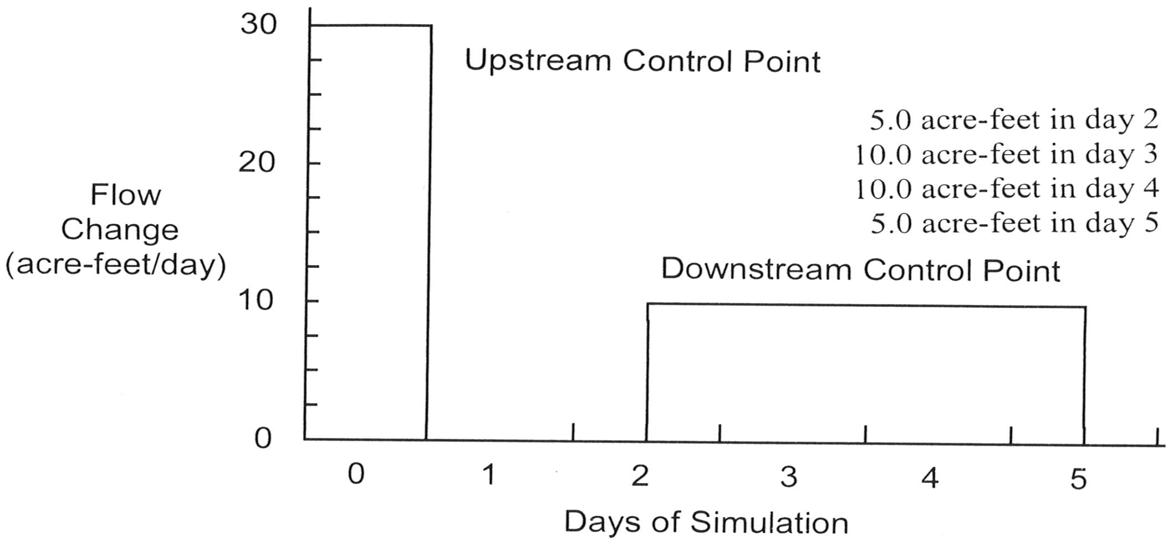
*Task 4* – The CPFLOW array employed in *Tasks 1A & 1B* is adjusted to reflect the water management actions of Task 3. **Routing is applied**.

## Methods for Routing (Lagging and Attenuating) the Daily Flow Changes Caused by Water Rights

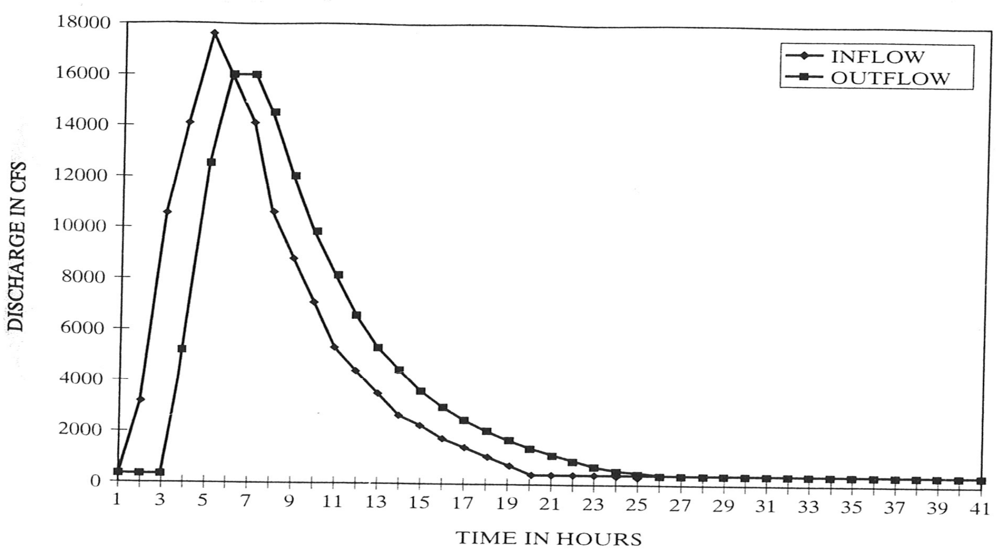
- If routing is employed, the lag and attenuation routing method is the recommended standard option. Parameters are lag LAG and attenuation ATT for normal flows (WR record changes) and lag LAGF and attenuation ATTF for flood flows (FR record changes).
- The Muskingum routing method with parameters x and K for normal flows and x and K for flood flows is also included in SIMD.
- Routing parameters are input on RT records described in Chapter 5 of the Users Manual (page 164) stored in the DIF daily input file.
- SIMD routing computations are explained in Chapter 3 of the Daily Manual. Methods for calibrating routing parameters are described in Daily Manual Chapter 4. Calibration programs DAY and DAYH are explained in Appendices A and B of the Daily Manual .

## Figure 3.1 Routing for LAG of 4.5 days and ATT of 3.0 days.

(Reference Manual Page 47 of Chapter 3 Routing and Forecasting)




## Conventional Hydrologic or Hydraulic Routing Employed in Models such as HEC-HMS and HEC-RAS



## Calibration of Routing Parameters

WRAP Daily Manual

Chapter 4 Routing Parameter Calibration
Appendix A – Program Daily Flows (DAY)
Appendix B – Program Daily Hydrographs (DAYH)

## Program DAY Statistical Analyses Comparing Changes in Observed Flows Between Gages

- Lag and attenuation metrics are computed for flow changes at USGS gages defined as reversals between increasing versus decreasing flows. Basic frequency statistics are computed for the dataset derived for the flows at pairs of gages.
- Lags in days can be expressed in terms of lag per mile. Attenuation may be approximated as one day.
- Abdul Siddiqui, *Routing Daily Flows through River Systems*, M.S. Thesis, TAMU, August 2017.

## Daily Brazos, Trinity, and Neches WAMs

*Daily Water Availability Model for the Brazos River Basin and San Jacinto-Brazos Coastal Basin*. Wurbs, TCEQ Contract 582-18-80410, TWRI TR-513, 238 pages, May 2019.

*Daily Water Availability Model for the Trinity River Basin*. Wurbs, TCEQ Contract 582-18-80410, 193 pages, December 2019.

*Daily Water Availability Model for the Neches River Basin*. Wurbs, TCEQ Contract 582-18-80410, 199 pages, June 2020.

## Number of Control Points

| Daily WAM | Total Number | Monthly IN Records | Daily Flows DF Records | Routing RT Records |
|---|---|---|---|---|
| Brazos | 3,152 | 77 | 58 | 67 |
| Trinity | 1,352 | 40 | 49 | 39 |
| Neches | 306 | 20 | 17 | 19 |

## Forecasting Stream Flow Availability for Water Supply and Future Channel Flow Capacity for Flood Control Operations

- Forecasting is relevant only if routing is activated.
- Forecasting employs an iterative algorithm repeated each day in which a forecast simulation covering a specified forecast period precedes the normal simulation for that day.
- Forecasting serves two purposes.
  1. Forecasts of future streamflow availability protects senior water rights from the earlier actions of upstream junior rights. Actions today affect water availability in later days.
  2. Forecasts of future stream channel capacities are used in flood control reservoir release decisions.

## Forecast Parameters on JU Record
(Users Manual Page 143)

FCST activates and deactivates forecasting.

FPRD sets the forecast period. The default forecast period is set at twice the longest routing path lag time.

APRD sets a global maximum limit on the flow availability forecast period which can be replaced for individual water rights by APERIOD(wr) on DW records.

## **Other JU Record Parameters Relevant to Routing and Forecasting** (Users Manual Page 143)

DFMETH - Monthly to daily flow distribution option. (Default flow pattern defined by DF record daily flows.)

DFFILE – Input file for DF record daily flows. (Default is DSS file.)

WRMETH – Final flow changes are placed at (1) the beginning versus (2) within the water right priority sequence. (Default is beginning.)

WRFCST – Forecast flow changes are placed at (1) beginning versus (2) within the water right priority sequence. (Default is beginning.)

NORT – option to specify no routing even if DIF file contains RT records. (Default routing activated by RT records in DIF file.)

## **Negative Incremental Flow Options** (JD Record ADJINC, Users Manual Page 39)

- Negative incremental flows are important in monthly SIM simulations and much more important in daily SIMD simulations.
- Flow adjustment options for dealing with negative incrementals in monthly or daily simulations are explained in Reference Manual Chapter 3. The section entitled *Negative Incremental Flow Options* in Daily Manual Chapter 3 (pages 42-44) focuses on daily simulations.
- Option selection parameter NEGINC is entered in JD record field 9 for either monthly or daily simulations. Option 7 is the recommended standard for daily simulations with forecasting. Option 6 is recommended for daily simulations if forecasting is not employed.

## Water Rights Analysis Package (WRAP)
## Daily Modeling System

## Module 4 – Reservoir Flood Control Operations

Presented by Ralph Wurbs, Ph.D., P.E.
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Sponsored by the

Texas Commission on Environmental Quality

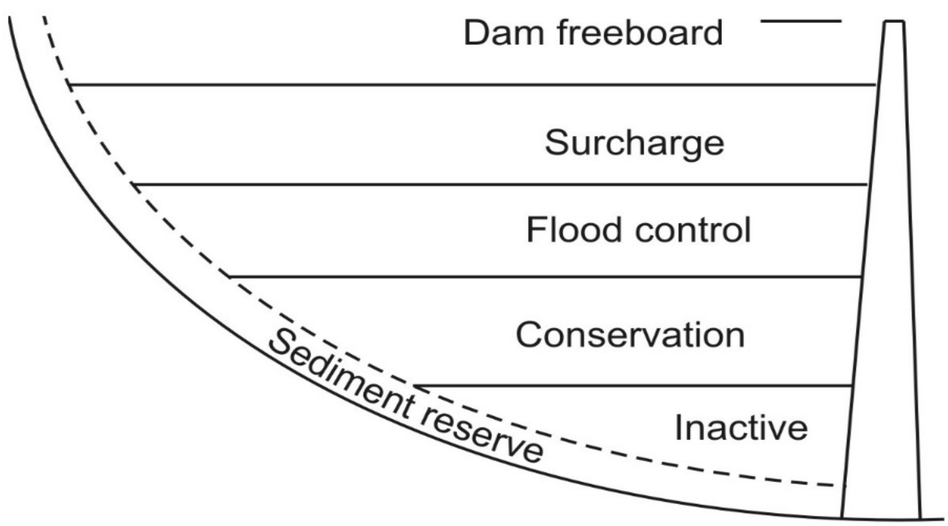
May 2021

## WRAP Daily Modeling System, TWRI TR-430, 4th Edition, January 2021.

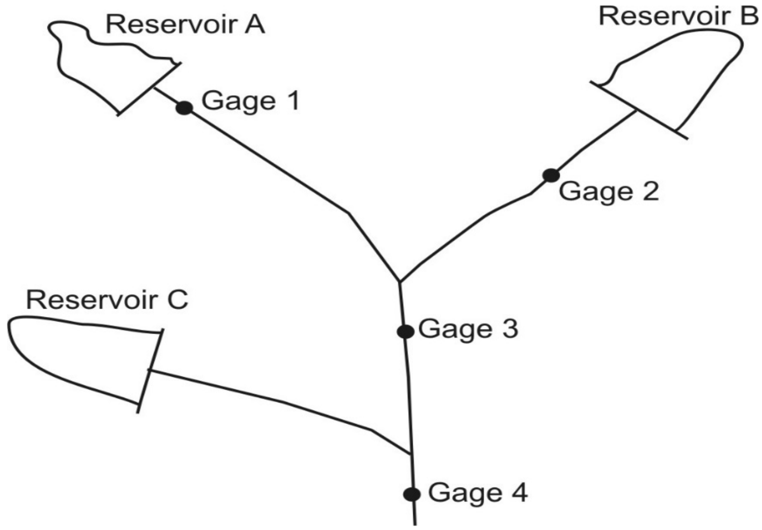
## Reservoir Operations During Floods

- Operation of designation flood control pools in flood control reservoirs based on stream flows at downstream gage sites (flood flow FF records) and outlet structure discharge capacities at the dams (FV/FQ record tables of reservoir storage versus outflow).
- Operation of water supply reservoirs with no designated flood control storage based only on outlet structure discharge capacities at the dams (FV/FQ record tables of reservoir storage versus outflow).

## Reservoir Pools



## Multiple-Reservoir System Flood Control Operations




## Reservoirs with Flood Control Pools

- International Boundary and Water Commission
  - Amistad: 2,977,000 ac-ft conservation; 1,744,000 ac-ft flood control
  - Falcon: 2,648,000 ac-ft conservation; 910,000 ac-ft flood control
- USACE Tulsa District
  - Texoma: 2,441,000 ac-ft conservation; 2,660,000 ac-ft flood control
- USACE Galveston District
  - Addicks Reservoir: 204,500 acre-feet flood control
  - Barker Reservoir: 207,000 acre-feet flood control
- USACE Fort Worth District
  - 25 multiple purpose reservoirs with flood control and water supply

## USACE FWD Reservoirs in Brazos, Trinity, and Neches Daily WAMs

| | Conservation (acre-feet) | Flood Control (acre-feet) |
|---|---|---|
| Brazos | | |
| Whitney | 636,100 | 1,363,400 |
| Aquilla | 52,400 | 93,600 |
| Waco | 206,562 | 519,840 |
| Proctor | 59,400 | 314,800 |
| Belton | 457,600 | 640,000 |
| Stillhouse | 235,700 | 394,700 |
| Georgetown | 37,100 | 93,700 |
| Granger | 65,500 | 178,500 |
| Somerville | 160,110 | 347,290 |

| | Conservation (acre-feet) | Flood Control (acre-feet) |
|---|---|---|
| Trinity | | |
| Benbrook | 88,250 | 76,550 |
| Joe Pool | 176,900 | 127,100 |
| Ray Roberts | 799,600 | 265,000 |
| Lewisville | 618,400 | 340,770 |
| Grapevine | 162,500 | 244,400 |
| Lavon | 456,500 | 291,600 |
| Navarro Mills | 63,300 | 148,900 |
| Bardwell | 54,900 | 85,100 |
| Neches | | |
| Sam Rayburn | 2,898,200 | 1,099,400 |

## SIMD and TABLES Input Records for Modeling and Analysis of Reservoir Operations during Floods

SIMD Input Records

- FR Record – flood control reservoir operations
- FF Record – flood flow limits
- FV Record – reservoir storage for storage/outflow table
- FQ Record – reservoir outflow for storage/outflow table

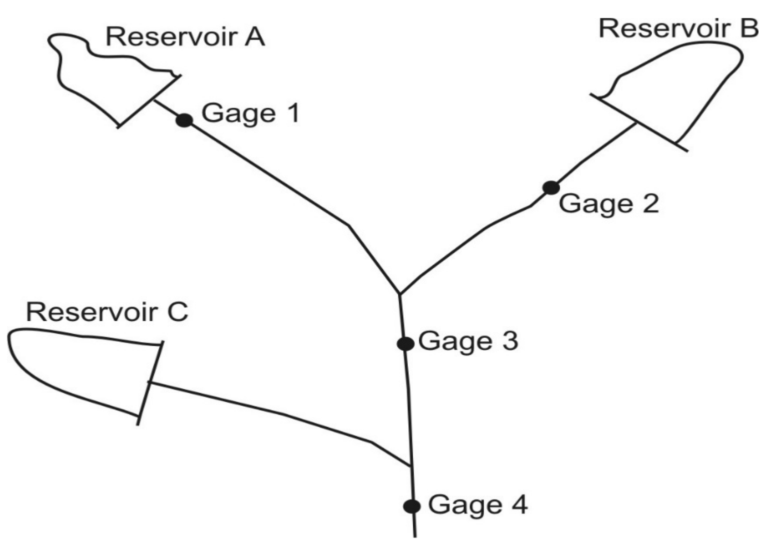
TABLES Input Record

FFA Record – flood frequency analysis of maximum annual daily reservoir storage, naturalized flow, and/or regulated flow from SIMD AFF file

## Flood Flow FF Record Variables

| Field | Description |
|---|---|
| 1 | Record identifier (FF) |
| 2 | Control point identifier |
| 3 | Flood flow limit in cfs |
| 4 | Maximum forecast period (default on JU record) |
| 5 | Flood index to connect to DI/IS/IP records |
| 6 | Optional water right identifier |

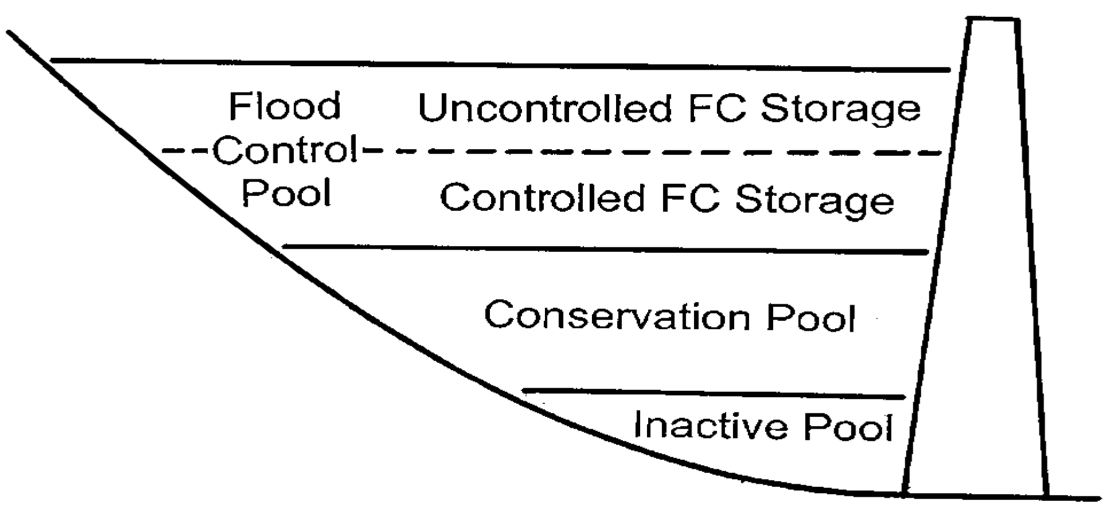
## Multiple-Reservoir System Flood Control Operations



## Multiple-Reservoir Release Decisions

$$\text{Rank Index} = (M)\left[\frac{\text{Storage Content}}{\text{Storage Capacity}}\right] + A$$

## Reservoir Pools Defined by SIMD WS and FR Records



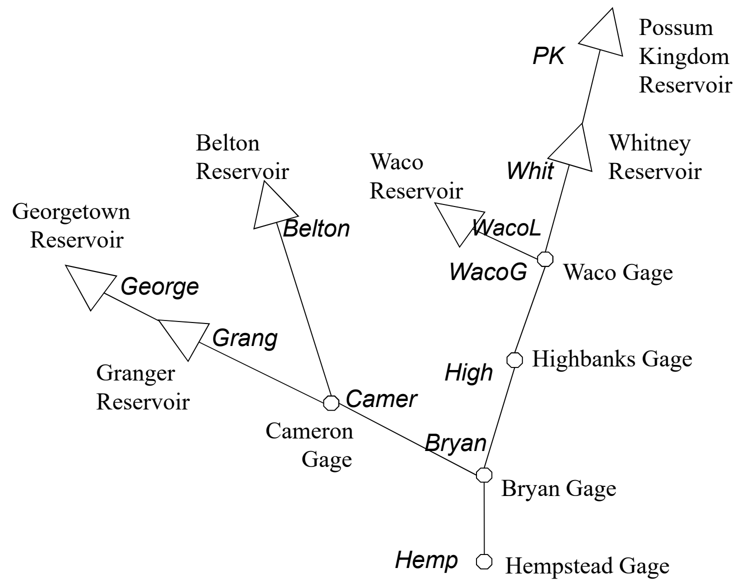
## Flood Control Reservoir FR Record Variables

| Field | Description |
|---|---|
| 1 | Record identifier (FR) |
| 2 | Control point identifier for reservoir |
| 4 | Storage priority number |
| 4 | Release priority number |
| 5 | Number of FF record limits, default = all |
| 6 | FCDEP option to exclude downstream cpts |
| 7 | FCMAX Maximum release in cfs |
| | Storage Volumes |
| 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 |
| | Multiple-Reservoir System Balancing |
| 11 | Multiplier factor M, default = 1.0 |
| 12 | Addition factor A, default = 0.0 |
| | Optional Water Right Identifiers |
| 13 | Water right identifier for storage right |
| 14 | Water right identifier for release right |

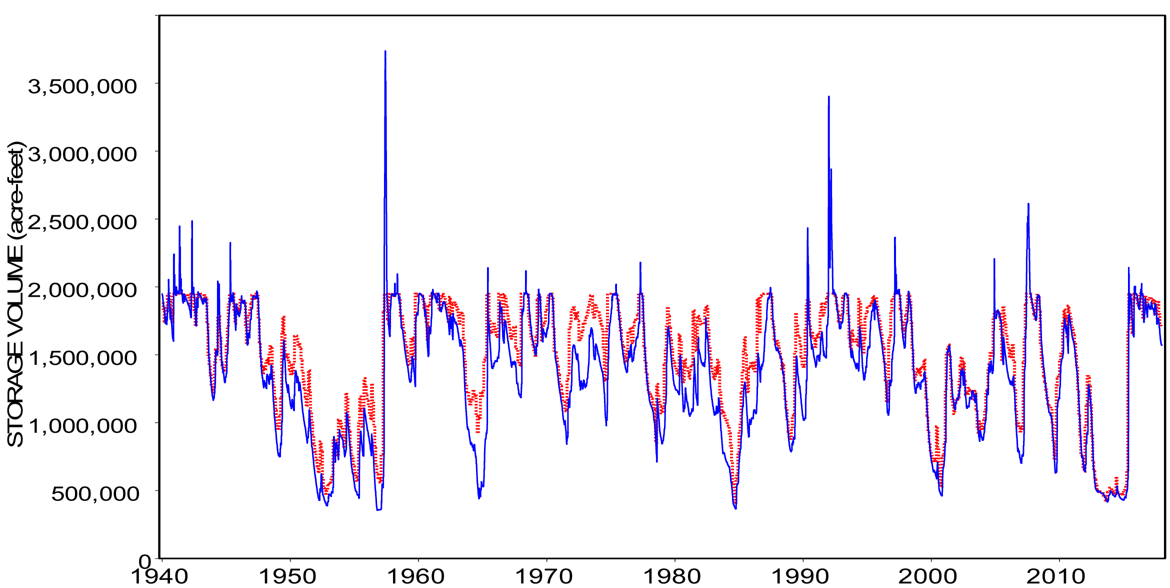
## Flood Storage Decisions and Release Decisions in Water Right Priority Sequence

- Storage Decision – Outlet gates are closed and inflows are stored in the flood control pool when a flood when a flood occurs.
- Release Decision – Releases are made to draw-down or empty the flood control pool as allowed by outlet and channel capacities.

## Example in Daily Manual (Figure 7.1 on Page 134)




## Storage Contents of Six Reservoirs for Monthly Simulation (red dots) and Daily Simulation with Flood Control (Figure 7.7 on Page 171)



## Records for Flood Control Operations (Daily Manual Page 140)

```
**  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    PK 570240. 588230. 606770. 625850. 645450. 665540.
FQ    PK      0.  10083.  22183. 34787.5  50417.  75625.
```

## Records in TABLES Input File of Example 9.4
(Table 9.10 on Daily Manual Page 274)

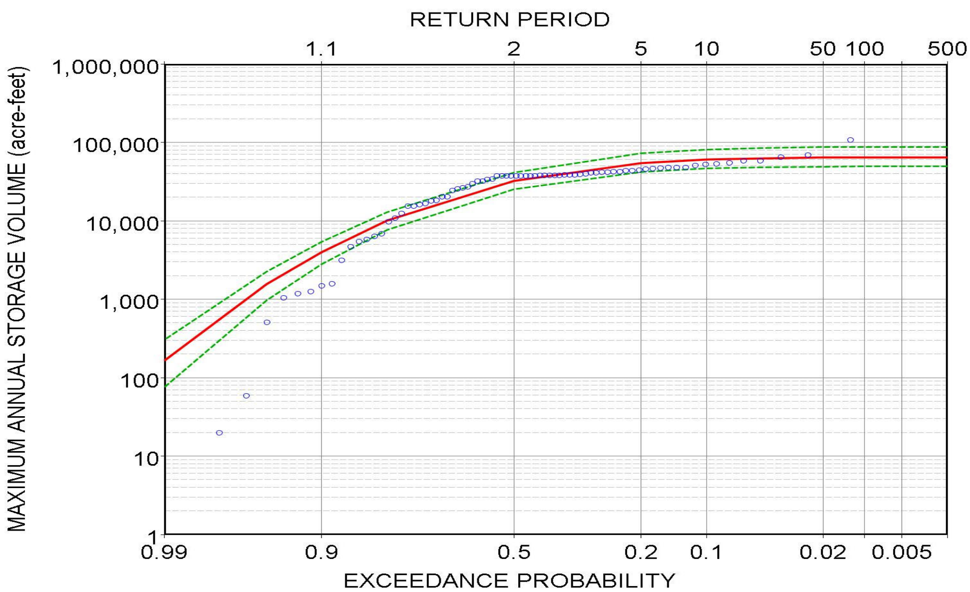
```
7FFA    4    2    0    6    6
IDEN        PK      Whit    WacoL   Belton   George    Grang
7FFA    4    2    1    6
IDEN        PK      Whit    WacoL   Belton   George    Grang
```

## 7FFA Record Frequency Analysis Results Illustrated by TABLES Output TOU File of Example 9.4

(Table 9.11 on Daily Manual Pages 275-277)

- Flood frequency analysis results table based on the log-normal distribution.
- Statistics computed for the original data and the logarithms of the data.
- Flood frequency analysis results table based on the log-Pearson type III distribution.
- Statistics computed for the original data and the logarithms of the data.
- Tabulation of data in ranked order along with Weibull probabilities.

## HEC-SSP Maximum Annual Storage Frequency Relationship for Georgetown Reservoir (Figure 9.14 on Page 286)



## Water Rights Analysis Package (WRAP) Daily Modeling System

## Module 5 – Senate Bill 3 Environmental Flow Standards

Presented by Ralph Wurbs, Ph.D., P.E.
Zachry Department of Civil and Environmental Engineering
Texas A&M University

Sponsored by the

Texas Commission on Environmental Quality

May 2021

## TCEQ Website with Information Regarding Senate Bill 3 (SB3) Environmental Flow Standards (EFS)

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

An environmental flow is an amount of water that should remain in a stream or river for the benefit of the environment of the river, bay, and estuary, while balancing human needs.

## Relevant Laws Enacted by Texas Legislature

- 1997 Senate Bill 1 (SB1) authorized the Water Availability Modeling (WAM) System and regional planning process.
- 2001 Senate Bill 2 (SB2) authorized the Texas Instream Flow Program (TIFP) consisting of studies to determine flow conditions necessary to support a sound ecological environment in the river basins of Texas.
- 2007 Senate Bill 3 (SB3) established a new regulatory process consisting of establishing environmental flow standards (EFS) that are incorporated in the WAM System. The EFS are developed through a stakeholder process culminating in TCEQ rulemaking.

## Process for Establishing Environmental Flow Standards (EFS) Pursuant to 2007 Senate Bill 3 (SB3)

- SB3 defines an environmental flow regime as a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific locations in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies.
- SB3 EFS for specified river systems are established by TCEQ based on recommendations of appointed expert science teams and stakeholder committees.

## Instream Flow Regime Components

*Subsistence Flows* Infrequent seasonal periods of low flows. (Maintain water quality criteria.)

*Base Flows* Normal flow conditions between storm events. (Ensure adequate habitat conditions, including variability, to support the natural biological community.)

*High Flow Pulses* Short-duration, high flows following storm events. (Maintain important physical habitat features. Provide longitudinal connectivity along the channel. Overbank flows also provide lateral connectivity between the river channel and floodplain.)

## WRAP Daily Modeling System, TWRI TR-430, 4th Edition, January 2021.

## WRAP Reference Manual
## TWRI TR-255, January 2021

Chapter 4 Water Management in the Simulation Model
Environmental Instream Flow Standards (pages 111-118)

## River Systems with SB3 EFS
(Reference Manual Table 4.3)

| River System | Priority Date | Stream Gages | Inflows to Bays |
|---|---|---|---|
| Sabine and Neches | April 2011 | 10 | 0 |
| Trinity and San Jacinto | April 2011 | 6 | 1 |
| Brazos | March 2012 | 19 | 0 |
| Colorado and Lavaca | August 2012 | 22 | 2 |
| Guadalupe & San Antonio | August 2012 | 17 | 2 |
| Nueces | February 2014 | 19 | 1 |
| Rio Grande | February 2014 | 4 | 0 |

## Hydrologic Conditions for SB3 EFS
(Reference Manual Table 4.4)

| | Hydrologic Conditions | |
|---|---|---|
| River System | Number | Variable |
| Sabine and Neches | 0 | none |
| Trinity and San Jacinto | 0 | none |
| Brazos | 3 | Palmer HDI |
| Colorado and Lavaca | 4 | 12-month flow |
| | 3 | reservoir storage |
| Guadalupe & San Antonio | 3 | 12-month flow |
| Nueces | 0 | none |
| Rio Grande | 4 | 12-month flow |

## Integration of Daily and Monthly WAMs
(Daily Manual Chapter 6 Page 132 and Chapter 8 Example and Developmental Brazos, Trinity, and Neches Daily WAMs)

- Daily targets for SB3 environmental flow standards are computed in a daily *SIMD* simulation and summed to monthly totals.
- The time series of monthly targets computed in the daily *SIMD* simulation are incorporated in the monthly *SIM* input dataset as target series *TS* record targets.

## SIM and SIMD Input Records for Modeling Instream Flow Requirements

- Users Manual Chapter 3 SIM (Pages 71-79)

  IF Record – Instream Flow Right
  **ES Record – Environmental Flow Standards**
  **HC Record – Hydrologic Conditions**
  **HI Record – Hydrologic Index**

- Users Manual Chapter 4 SIMD (Pages 153-159)

  **PF Record – High Pulse Flow Component of EFS**
  **PO Record – Pulse Flow Supplement Options**

- Users Manual Chapter 3 SIM

  UC, WS, DI/IP/IS, SO, and TO records may be used with either IF or WR record water rights.

## EFS for Gage on the Little River at Cameron

(Table 8.1 on Page 194 of Daily Manual)

| | Subsistence | Hydrologic | Base | | Seasonal Pulse | |
|---|---|---|---|---|---|---|
| Season | Flow | Condition | Flow | Dry Condition | Average Cond. | Wet Condition |
| | 32 cfs | Dry | 110 cfs | 1 per season | 3 per season | 2 per season |
| Winter | -0- | Average | 190 cfs | Trigger 1,080 cfs | Trigger 1,080 cfs | Trigger 2,140 cfs |
| | -0- | Wet | 460 cfs | Volume 6,680 af | Volume 6,680 af | Volume 14,900 af |
| | | | | Duration 8 days | Duration 8 days | Duration 10 days |
| | 32 cfs | Dry | 140 cfs | 1 per season | 3 per season | 2 per season |
| Spring | -0- | Average | 310 cfs | Trigger 3,200 cfs | Trigger 3,200 cfs | Trigger 4,790 cfs |
| | -0- | Wet | 760 cfs | Volume 23,900 af | Volume 23,900 af | Volume 38,400 af |
| | | | | Duration 12 days | Duration 12 days | Duration 14 days |
| | 32 cfs | Dry | 97 cfs | 1 per season | 3 per season | 2 per season |
| Summer | -0- | Average | 160 cfs | Trigger 560 cfs | Trigger 560 cfs | Trigger 990 cfs |
| | -0- | Wet | 330 cfs | Volume 2,860 af | Volume 2,860 af | Volume 5,550 af |
| | | | | Duration 6 days | Duration 6 days | Duration 8 days |

## DAT File Input Records for IF Record Water Right
(Table 8.4 on Page 198 of Daily Manual)

```
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.
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 Record Input Parameters (Users Manual Pages 71-73)

CD – Instream flow record identifier IF
CP – Control point
AMT – Annual target amount if ES, HC, and PF not employed.
Targets are set by ES, HC, and PF records (-9)
ES record targets are tabulated in MSS file (-99)
USE – Distribution of annual target to monthly (not used with ESF)
WRNUM – Priority number
IFM(1) – Include or exclude reservoir releases in instream flow limit
IFM(2) – Junior, largest, or smallest for multiple IF record rights
IFM(3) – Second pass and storage options
FSCV – Identifier connecting to FS or CV record
DINDEX – Drought index
WRID and WRIDS – Water right identifiers

## ES Record – Environmental Flow Standards
(Users Manual Pages 74-76)

CD – Record identifier ES

ESF – Flow Regime Components

- SUBS Subsistence flow
- SF50 Subsistence flow with 50% rule
- BASE Base flow
- HAnn High flow. Maximum of nn periods/year
- HSnn HSnn. Maximum of nn periods/season
- PFES PF record pulse flows only

ESHC – Hydrologic condition defined by HC record

ESQ – 12 Mean monthly flow rate limits in cfs for Jan-Dec

ESQX – ESQ multiplier factor

## HC Record - Hydrologic Conditions Referenced by ES and PF Records
(Users Manual Page 77)

CD – Record identifier HC
CPHC – Control point identifier
ESV – Variable used to select regime component (Default is regulated flow at priority of water right)
HCV – Variable used to define hydrologic conditions (RF, RR, NF, ST, HI, WR)
NHCM – Number of preceding months for summation
HCM(1-12) – Months to update hydrologic condition (Jan-Dec)
HCL(1-9) – Limits defining hydrologic conditions

## PF Record – High Pulse Flow Components of EFS
(Users Manual Pages 153-156)

Flow Variable – regulated with or without releases, naturalized
Hydrologic Condition – defined by HC record
Trigger – daily flow trigger in cfs that initiates pulse event
Volume – total flow volume criterion in acre-feet
Duration – duration criterion in days for ending pulse
Frequency – number of pulse events per tracking period
Tracking period – seasonal or number of days
Season Start Month and Season End Month
Season Count – one or multiple seasons in frequency count
Flow Option – latest or end-of-period regulated flow
Target Limit – whether targets constrained to not exceed trigger
Target Selection – latest, largest (default), smallest, add

## PO Record – Pulse Flow Supplemental Options
(Users Manual Pages 157-159)

- Pulse event ignition options
- Pulse event termination options
- Pulse event volume and frequency options
- Other initiation and termination options

## Options for Combining Multiple Instream Flow Targets at Same Control Point

| IF Record | PF Record | Combining Options |
|---|---|---|
| 1 (default) | 1 | Junior target replaces senior target. |
| 2 | 2 (default) | Largest target is adopted. |
| 3 | 3 | Smallest target is adopted. |
| - | 4 | The two targets are added together. |

## Instream Flow Targets and Shortages by Water Right or Control Point in Simulation Results

(OF Record, Users Manual Pages 45-47)

IF Record Instream Flow Water Rights

TIF – target before combining with other targets

IFT – target after combining targets

IFS – shortage for combined target

Control Point

IFT – final instream flow target at control point

IFS – final instream flow shortage at control point

## Frequency Statistics for EFS Target Components (Table 8.25)

| | 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 |
| standard dev (cfs) | 194.7 | 842.3 | 827.0 | 856.7 | 1,125 | 1,251 |
| | Targets in cfs with Specified Exceedance Frequencies | | | | | |
| 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 |

## EFS for Gage on Brazos River Near Hempstead
(Table 8.1 on Page 195 of Daily Manual)

| Season | Subsistence Flow | Hydrologic Condition | Base Flow | Seasonal Pulse Dry Condition | Seasonal Pulse Average Condition | Seasonal Pulse Wet Condition |
|---|---|---|---|---|---|---|
| | 510 cfs | Dry | 920 cfs | 1 per season | 3 per season | 2 per season |
| Winter | -0- | Average | 1,440 cfs | Trigger 5,720 cfs | Trigger 5,720 cfs | Trigger 11,200 cfs |
| | -0- | Wet | 2,890 cfs | Volume 49,800 af | Volume 49,800 af | Vol. 125,000 af |
| | | | | Duration 10 days | Duration 10 days | Duration 15 days |
| | 510 cfs | Dry | 1,130 cfs | 1 per season | 3 per season | 2 per season |
| Spring | -0- | Average | 1,900 cfs | Trigger 8,530 cfs | Trigger 8,530 cfs | Trigger 16,800 cfs |
| | -0- | Wet | 3,440 cfs | Volume 85,000 af | Volume 85,000 af | Vol. 219,000 af |
| | | | | Duration 13 days | Duration 13 days | Duration 19 days |
| | 510 cfs | Dry | 950 cfs | 1 per season | 3 per season | 2 per season |
| Summer | -0- | Average | 1,330 cfs | Trigger 2,620 cfs | Trigger 2,620 cfs | Trigger 5,090 cfs |
| | -0- | Wet | 2,050 cfs | Volume 17,000 af | Volume 17,000 af | Vol. 40,900 af |
| | | | | Duration 7 days | Duration 7 days | Duration 9 days |

## DAT File Input Records for IF Record Water Right
(Table 8.4 on Page 198 of Daily Manual)

```
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.
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
```

## Beginning of ES Record Target Results Table from MSS File
(Table 8.7 Page 205)

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.

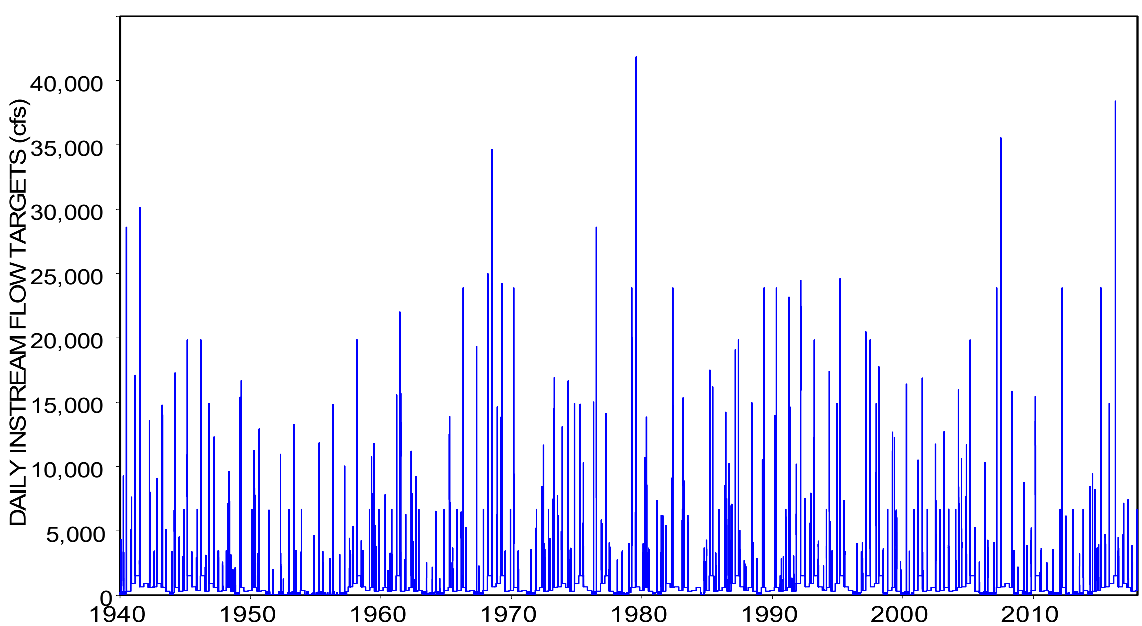
## Beginning of PF Record Target Results Table from SMM File
(Table 8.17 Page 219)

Pulse Flow Target Computation Tracking Tabulation

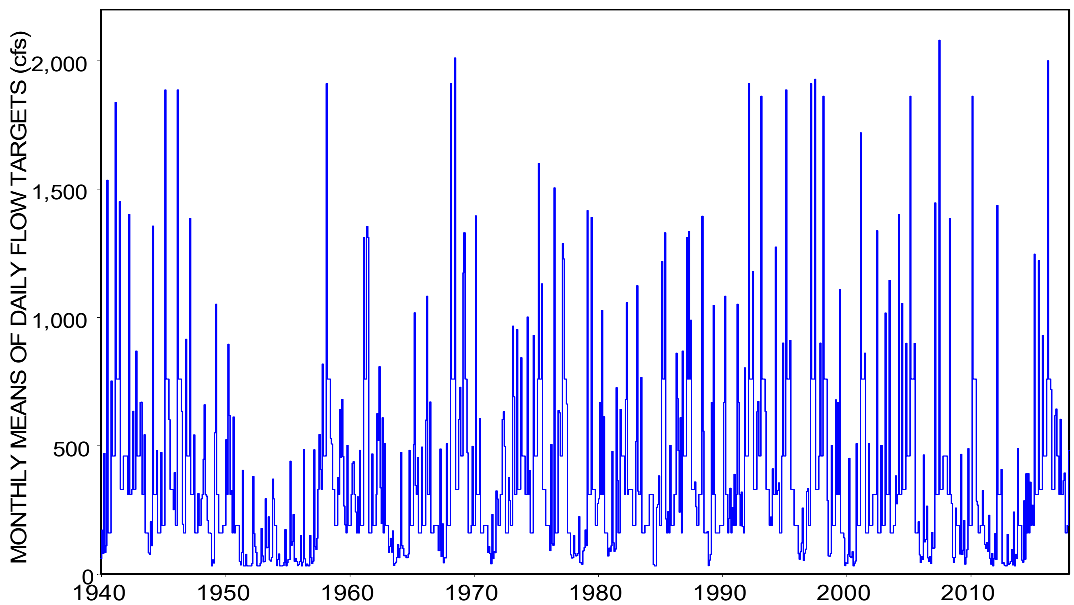
Pulse flow variable (PFV), PFV cumulative volume, and target amounts are in acre-feet/day.
Targets include targets from ES or other preceding records, the pulse flow target, and final adopted target.
Pulse count is the number of pulse events during tracking period defined by PF record fields 8-11.

| 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 |

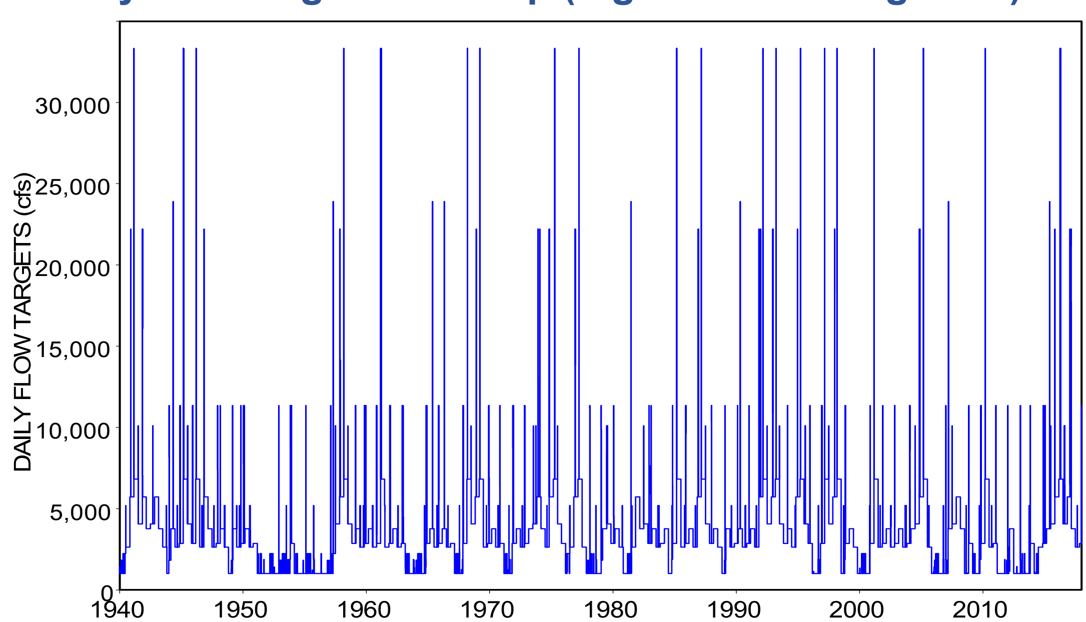
## Daily EFS Targets at Camer (Figure 8.7 on Page 242)



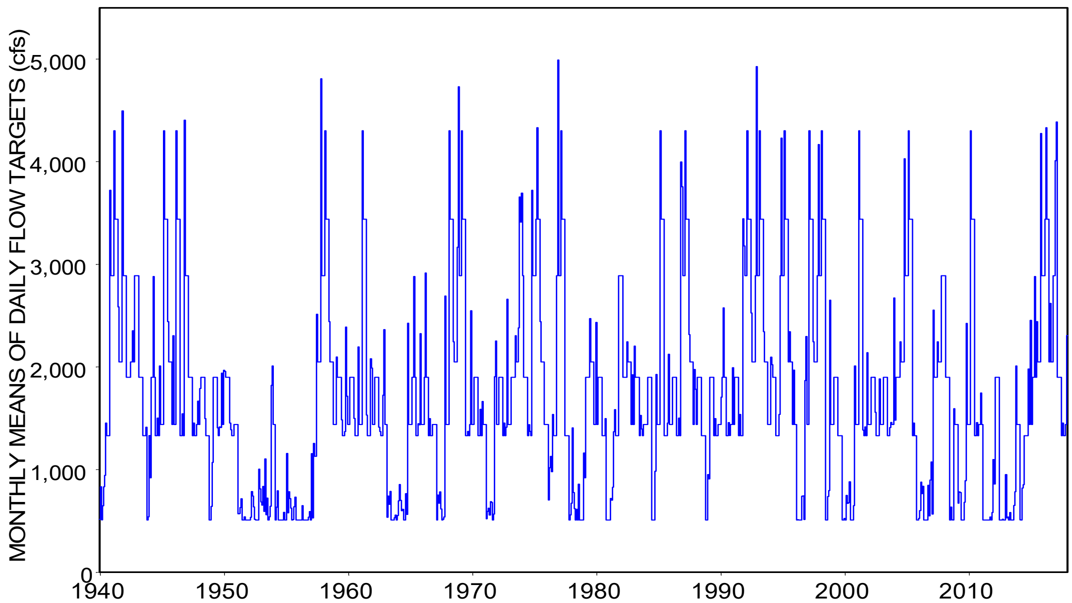
## Monthly EFS Targets at Camer (Figure 8.8 on Page 242)




## Daily EFS Targets at Hemp (Figure 8.9 on Page 243)



## Monthly EFS Targets at Hemp (Figure 8.10 on Page 243)




## WRAP Daily Modeling System Course Modules

1. Introductory Overview of Daily Features
2. Conversion of Monthly Datasets to Daily
3. Routing and Forecasting
4. Flood Control Reservoir Operations
5. SB3 Environmental Flow Standards