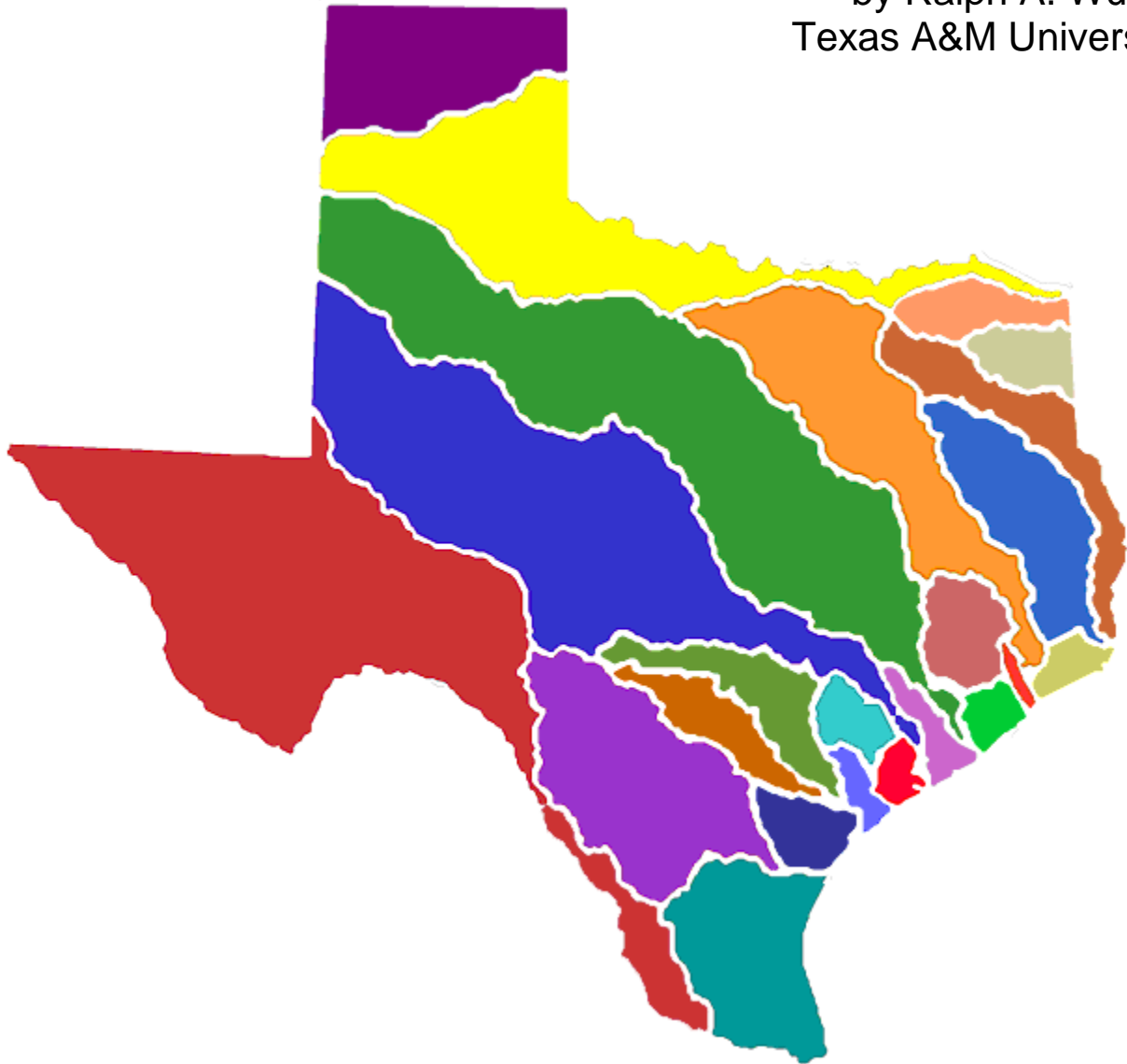


# Water Rights Analysis Package (WRAP) River System Hydrology

by Ralph A. Wurbs  
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# **Water Rights Analysis Package (WRAP)**

## **River System Hydrology**

by

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## CHAPTER 1 INTRODUCTION

The Water Rights Analysis Package (WRAP) is documented by a *Reference Manual* [1], *Users Manual* [2], and several auxiliary manuals [3, 4, 5, 6, 7] including this *Hydrology Manual* [4]. [Numbers in brackets refer to the list of references at the end of this manual.] This *Hydrology Manual* focuses specifically on the WRAP computer program *HYD*. The purpose of *HYD* is to facilitate developing hydrology-related monthly time series input data for the WRAP simulation models *SIM* and *SIMD*. This *Hydrology Manual* explains *HYD* methodologies and the use of *HYD* with *HEC-DSSVue* and the other WRAP programs. The *Hydrology Manual* is written assuming that the reader is already familiar with the WRAP *Reference* and *Users Manuals*.

### **Hydrology Input for the WRAP Program *SIM***

Hydrology input files for a *SIM* simulation consist of monthly naturalized stream flows and monthly reservoir surface evaporation less precipitation rates at pertinent locations covering a hydrologic period-of-analysis. The 20 datasets for individual river basins in the Texas Commission on Environmental Quality (TCEQ) Water Availability Modeling (WAM) System include naturalized flows at a total of about 500 sites, most of which are U.S. Geological Survey (USGS) stream gaging stations. These flows are distributed to over 12,000 other ungaged control points within the *SIM* simulation. Simulation period-of-analysis sequences of monthly net evaporation-precipitation rates for the 20 WAM datasets are assigned to a total of about 310 control points representing reservoir locations.

The datasets in the TCEQ WAM System were originally developed by the TCEQ and its contractors during 1998-2001. The original sequences of naturalized flows and net evaporation-precipitation rates extend from either 1934, 1940, or 1948 through either 1989, 1996, 1997, 1998, or 2000. As of May 2019, other than case study investigations performed at Texas A&M University, *HYD* has been applied very little to date because the WAM System hydrology datasets had already been developed before *HYD* became available. However, updating the hydrologic periods-of-analysis to the present with continuing updates in the future is important. *HYD* provides capabilities for updating existing datasets as well as creating new datasets.

Evaporation from a reservoir and precipitation falling directly on the reservoir water surface are combined as net evaporation minus precipitation. Net evaporation less precipitation volumes are computed within the *SIM* simulation by multiplying the reservoir water surface area by net evaporation-precipitation rates (depths/month) provided in a *SIM* input file. Program *HYD* provides sets of options for developing the *SIM* input file of net evaporation-precipitation rates from datasets of observed monthly evaporation depths and precipitation depths.

A *SIM* simulation begins with homogeneous sequences of monthly stream flow volumes covering the hydrologic period-of-analysis at all control points. Program *HYD* provides sets of optional routines for developing or updating homogeneous historical stream flow datasets for input to *SIM*. For each control point, stream flows must be either provided as input to *SIM* or computed within *SIM* from flows at one or more other control points using the flow distribution techniques described in Chapter 3 of the *Reference Manual* that are incorporated in both the WRAP pre-simulation program *HYD* and the WRAP simulation program *SIM*.

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

The stream flows in the *SIM* input dataset (*IN* records in a FLO file or DSS file) usually are naturalized flows representing natural hydrology unaffected by water resources development and management. Alternatively, the stream flow inflows input to the river/reservoir system simulation model may represent some other specified homogeneous condition of river basin development. The basic concept is to provide a homogeneous set of flows as input to *SIM* representing hydrology for a specified condition of river basin development. The stream flows in the *SIM* input dataset should represent flows unaffected by the reservoirs, diversions, return flows, and other water management practices and water use reflected in the *SIM* water rights input dataset. Typically, *SIM* stream flow input datasets represent natural hydrology without human impact but alternatively, as discussed in Chapter 4, may reflect other scenarios of river basin hydrology. The term *naturalized* flow is applied generically in the WRAP manuals to refer to any stream flows adopted for *SIM* input.

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

Observed flows at stream gaging stations with watersheds that have experienced little or no development may be adopted for direct use as naturalized flows representing natural conditions of river basin hydrology without human water use. However, population growth and economic development and accompanying water resources development and use significantly affect flows of most major rivers in Texas and elsewhere. Differences between computed naturalized flows and actual gaged flows at many sites may be very significant.

### **Capabilities Provided by the WRAP Program *HYD***

The *HYD*rology data program provides a set of routines that create, extend, update, modify, and/or analyze sequences of naturalized or otherwise adjusted monthly stream flows, net reservoir surface monthly evaporation less precipitation depths, or other hydrologic time series variables. Although *HYD* is motivated primarily by naturalized flows and reservoir net evaporation-precipitation rates, many of the *HYD* data management and analysis routines are applicable to other related time series variables such as precipitation depths, evaporation depths, observed stream flows, simulated flows, flow adjustments, and drought indices. *HYD* is designed for compiling, manipulating, and analyzing sequences of monthly quantities. Monthly quantities can also be aggregated to annual time series quantities and analyzed with *HYD*. Compilation and use of daily stream flow sequences in the WRAP programs *DAY*, *SIMD*, and *TABLES* and associated program *HEC-DSSVue* is covered in the *Daily* and *Users Manuals*.

### Products Created with the WRAP Program HYD

A primary *HYD* output is sets of *IN* and *EV* records containing naturalized flow volumes (*IN* records) and reservoir net evaporation-precipitation depths (*EV* records) stored as *SIM* input FLO and EVA files or a *SIM* hydrology input DSS file. Datasets of other types of *SIM* input records can also be generated with *HYD*. Program *HYD* can also be employed to perform various types of statistical analyses of series with results displayed in output tables. *HYD* reads and creates both DSS and text files. *HEC-DSSVue* is employed with *HYD* to plot and analyze time series data. Options are also provided in both *HYD* and *HEC-DSSVue* for reading and writing data as columns in a table, which facilitates transferring the data from and to spreadsheet programs such as Microsoft Excel.

Although other types of time series may be created as well, a primary output provided by *HYD* consists of one or both of the following two separate *SIM* hydrology input datasets.

- sequences of monthly naturalized or otherwise adjusted stream flow volumes designed for input to *SIM* as *IN* records in a file with filename extension FLO or DSS
- sequences of monthly reservoir surface net evaporation less precipitation depths which are input to *SIM* as *EV* records a file with filename extension EVA or DSS

*IN* and *EV* records are stored in separate FLO and EVA files or together in a single DSS file. The monthly stream flow volumes and net evaporation-precipitation depths cover a specified hydrologic period-of-analysis and are located at specified control points. *HYD* also works with other types of data and provides options to organize datasets in various alternative formats.

The daily simulation model *SIMD* contains all of the capabilities of the monthly simulation model *SIM* plus major additional features described in the *Users* and *Daily Manuals* [2, 5]. *SIMD* reads the same monthly hydrology data from the same input files as *SIM*. A daily simulation can be performed with daily simulation results aggregated to monthly within *SIMD* and recorded in the *SIMD* monthly output OUT file. *HYD* and this *Hydrology Manual* deal with time series of monthly quantities, which can be monthly input or output data for either *SIM* or *SIMD*.

### Organization of Program HYD and this Manual

The WRAP program *HYD* is a collection of different sets of methodologies that can be employed entirely separately from each other or in various combinations. *HYD* capabilities are employed in collaboration with *HEC-DSSVue*, *SIM/SIMD*, and *TABLES*. The present Chapter 1 provides an introductory overview of *HYD*. Chapters 2, 3, 4, 5, and 6 each cover different sets of data management and computational options. Chapter 7 is a compilation of instructions for creating *HYD* input HIN file records for applying the methods described in Chapters 3 and 4. Chapter 8 provides instructions for developing *HYD* input records for using the methods described in Chapters 5 and 6.

Chapter 2 discusses hydrology data sources and *HYD* capabilities for statistical trend analyses of time series and conversion of datasets between DSS files and text files in various formats. The methods described in Chapter 2 are applied using *HYD* input HIN file records also described in Chapter 2.

Chapter 3 describes *HYD* features for creating *SIM* hydrology input files (with filename extensions FLO, EVA, or DSS) from observed data.

- Sequences of monthly naturalized flows recorded on *IN* records are developed from observed flows using options controlled by *AN*, *AS*, *CI*, *CP*, *EQ*, *FA*, *FC*, *FD*, *MF*, *RS*, *SA*, *SC*, *SV*, *WP*, and *XL* records in the *HYD* input HIN file.
- Sequences of monthly net evaporation less precipitation rates on *EV* records are developed from observed evaporation and precipitation rates using options controlled by evaporation-precipitation *EP* records in the *HYD* input HIN file.

Chapter 4 describes *HYD* features for developing flows using *SIM* simulation results from a *SIM* output OUT file to develop *SIM* input file datasets.

- Output-input *OI* records in a *HYD* input HIN file may be used to develop sets of various types of *SIM* input records from data in a *SIM* output OUT file.
- Naturalized flow sequences may be extended with *HYD* by using *SIM* simulation results to adjust observed stream flows.
- Flows representing a specified condition of water resources development and use may be computed with *HYD* from *SIM* simulation results for incorporation in a condensed *SIM* input dataset.

Chapters 5 and 6 describe *HYD* features for updating *SIM* hydrology input files using precipitation and evaporation datasets maintained by the Texas Water Development Board (TWDB).

- Chapter 5 covers features for compiling sequences of monthly evaporation-precipitation rates from observed evaporation and precipitation rates from the datasets maintained by the TWDB as specified by *EE*, *EX*, *QD*, and *QA* records described in Chapter 8 entered in the *HYD* input HIN file.
- Chapter 6 describes a precipitation-streamflow model and procedures for calibrating and then applying the model to extend naturalized flow sequences as specified by *FE*, *QD*, *QA*, *FP*, *BM*, *B1*, *B2*, *B3*, *B4*, *XP*, *X1*, *X2*, *X3*, *X4*, *FX*, *UB*, *FR*, and *FZ* records described in Chapter 8 provided in the HIN file.

Chapters 7 and 8 provide instructions for creating *HYD* input HIN file records required to implement the methods described in Chapters 3 and 4 and Chapters 5 and 6.

The original *HYD* created during 1999-2001 focused on developing sequences of *SIM* input *IN* and *EV* records employing the methods documented in Chapters 3 and 7. The computer program was expanded during 2007-2008 to add the methods presented in Chapters 4 and 7. The hydrologic period-of-analysis extension strategy and methods described in Chapters 5, 6, and 8 was originally developed during 2011-2013. Data management and statistical analysis capabilities presented in Chapter 2 are the most recent additions to *HYD*.

*HYD* input and output files are discussed in the last section of Chapter 1. *HYD* input files contain a set of records controlling various options and supplying the data to be used in the computations. Explanations of input records used with features described in Chapter 2 are included in Chapter 2. Instructions for the various types of input records associated with the capabilities introduced in Chapters 3 and 4 are provided in Chapter 7. The input records that control procedures presented in Chapters 5 and 6 for updating hydrologic simulation periods are covered in Chapter 8.

### Program HYD Capabilities

*HYD* is comprised of various options for managing and manipulating time series data stored in either text files or DSS files. Options covered in Chapter 2 provide general capabilities for compiling, accessing, converting, and analyzing hydrology data that are not necessarily restricted to a specific use of the generated datasets or statistics. The features documented in the other chapters focus on developing or updating/extending *SIM* (and/or *SIMD*) monthly time series input data.

The *HYD* routines covered in Chapter 3 employ conventional WAM concepts to create datasets of *SIM* input *IN* and *EV* records (FLO, EVA, DSS files). The Chapter 3 methods can be used to create new datasets or to update/extend and/or improve existing datasets of *IN* and *EV* records. Chapter 4 introduces non-conventional methods for adjusting stream flows using existing WAM datasets. Chapter 6 presents a new strategy for extending hydrologic period-of-analysis sequences of monthly naturalized flows (*IN* records) based on a physically-based regression model relating monthly naturalized flows to monthly precipitation and evaporation. Chapter 5 covers *HYD* features for the companion task of extending *EV* record net evaporation-precipitation depths.

Program *HYD* creates a *SIM* input FLO file by adjusting sequences of observed monthly stream flow volumes as described in Chapter 3, controlled by the input records in Chapter 7. Sequences of historical water supply diversions, return flows, reservoir net evaporation and storage changes, and other related data may be provided as monthly flow volume adjustment input to *HYD* along with observed flows. *HYD* includes capabilities for computing reservoir evaporation volume adjustments based on the same reservoir volume/area input data used in *SIM*. *HYD* can work with spring flow adjustments on *FA* records that are stored in a *SIM* input FAD file.

*HYD* reads input sequences of monthly evaporation rates, precipitation rates, or net evaporation less precipitation rates as monthly depths and manipulates these data as necessary to create *SIM* evaporation-precipitation input datasets. *HYD* manipulations of these data, as covered in Chapters 2, 3, and 5, include combining operations and changing the organization of the datasets.

Control point *CP* input records are similar in *HYD* and *SIM*. *CP* records from a *SIM* input DAT file can be copied to a *HYD* input HIN file and visa versa. Naturalized flows read as input for some control points (typically gaged sites) may be distributed to other control points (ungaged sites) using the same methods within either *HYD* or *SIM* based on control point *CP* record parameters and information from a flow distribution DIS file. The format and content of the flow distribution DIS file and its input records are the same for both *HYD* and *SIM*.

*HYD* can also read various simulation results from a *SIM* or *SIMD* monthly output *OUT* file as discussed in Chapter 4. The variables read from the *OUT* file may be written by *HYD* to a *HYD* output file in the same standard format as *IN* and *EV* records but with a user-specified record identifier. For example, monthly environmental flow targets summed from daily targets in a daily *SIMD* simulation may be converted by *HYD* to target series *TS* records stored in a *HYD* output *HOT* file which is then converted to a *SIM* input TSF file by simply changing the filename extension.

Chapter 4 describes *HYD* capabilities for developing a set of flows representing a specified scenario of water development/use from *SIM* simulation results. Variables read from a *SIM* output *OUT* file and a couple of related variables computed from them can be used with *HYD* stream flow

adjustment specifications *AS* records to adjust stream flows. Thus, strategies may be adopted to develop *SIM* stream inflows (*IN* records) representing specified conditions of river basin development based on adjustments derived from *SIM* simulation results. Applications of these *HYD* features covered in Chapter 3 include (1) extending naturalized flows and (2) developing condensed *SIM* datasets that focus on particular water management systems.

Chapters 5, 6, and 8 describe strategies for updating the hydrologic periods-of-analysis for the TCEQ WAM System datasets based on precipitation and evaporation datasets maintained by the Texas Water Development Board (TWDB) on a one degree quadrangle basis for the entire state of Texas. The TWDB datasets are described in Chapter 2. Chapter 5 deals with extending sequences of net evaporation-precipitation rates. Chapter 6 describes a model for extending naturalized flows using the same TWDB database. Input records are described in Chapter 8.

Naturalized flows are synthesized using a physically based regression model described in Chapter 6 that converts precipitation to stream flow. Parameters for the flow synthesis model are calibrated based on naturalized flows from the WRAP input dataset covering the original hydrologic period-of-analysis and precipitation and evaporation depths from the statewide TWDB datasets. The flow model is then applied to compute flows for the period of the extension based on precipitation and evaporation depths from the TWDB statewide datasets.

### **HEC-DSS and HEC-DSSVue**

The Hydrologic Engineering Center (HEC) Data Storage System (DSS) and HEC-DSS Visual Utility Engine (*HEC-DSSVue*) interface have been integrated with the WRAP programs as outlined in Chapter 6 of the *WRAP Users Manual*. *HYD* reads data from DSS files and creates and writes data to DSS files. The times series data input to or output from *HYD* are plotted with *HEC-DSSVue*. Statistical analyses are performed with either *HEC-DSSVue* or the WRAP programs *HYD*, *TABLES*, or *DAY* as outlined in Chapter 9 of the *WRAP Daily Manual* and discussed throughout the *Reference*, *Users*, *Fundamentals*, *Daily*, and *Hydrology Manuals*.

*HEC-DSS* and *HEC-DSSVue* are designed for efficiently working with datasets of time series data, including extremely large datasets. *HEC-DSSVue* is explained in detail by a User's Manual [8] available at the HEC website with the software. <http://www.hec.usace.army.mil/>

Conventional WRAP applications of DSS files and *HEC-DSSVue* are discussed throughout this *Hydrology Manual* and the other WRAP manuals. Other additional expanded applications of DSS files and *HEC-DSSVue* in combination with *HYD* routines for developing, updating, and improving WRAP hydrology datasets could significantly contribute to enhancing water availability modeling capabilities in the future.

### **Time Series Arrays**

The program *HYD* consists of sets of routines for creating, manipulating, and writing data arrays. *HYD* data management and computational operations work with time series datasets stored in computer memory as arrays. The routines described in Chapter 2 read monthly quantities for any time series variable which are stored in monthly time series data array *MTS* indexed as follows, which can also be optionally converted to an annual data array *ATS*.

*MTS (time series identifier, year, month)* and *ATS (time series identifier, year)*

Chapters 3 through 8 deal with a *FLOW* array of monthly stream flow volumes and *EP* array of monthly evaporation, precipitation, or net evaporation-precipitation depths indexed as follows.

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

The arrays are initially populated with data read by *HYD* from input files in accordance with specifications on the *HS* record (Chapter 2) or the *JC* record (Chapters 3 through 8). *HS* and *JC* record parameters also specify the format and organization of the output files to which the arrays are written at the end of the *HYD* execution. Operations with the *MTS* array during an execution of *HYD* are defined by the *HS* record described in Chapter 2. Adjustments to the *FLOW* and *EP* arrays during an execution of *HYD* are controlled by the various *HIN* file input records described in Chapters 7 and 8 as explained in Chapters 3 and 4 and Chapters 5 and 6.

### **Input and Output Files**

Most *HYD* input filenames (*root.extension*) all have the same root, denoted here as *root1*, and extensions indicating the type of data in each file. *HYD* output filenames have a common root, denoted here as *root2*, and extensions representing type of data. The root (*root2*) selected for the filenames of the output files may be different than the input file root (*root1*).

The user assigns the roots for the input (*root1*) and output (*root2*) filenames during the login procedure that may be managed through the *WinWRAP* interface. If the user chooses to not enter *root2*, the default automatically adopted by *HYD* is to create *root2* by appending the phrase *OUT* to *root1*. Thus, the default for *root2* is *root1OUT*. For example, if the filename root *Example* is entered for input files but the filename root for output files is left blank, the *FLO* input file and *FLO* output file will have the filenames *Example.FLO* and *ExampleOUT.FLO*, respectively.

The basic *HYD* input file with filename extension *HIN* is required. The message file with filename extension *HMS* is always created automatically. The *HOT* file is a general purpose output file. The other input and output files are provided as needed depending upon the tasks being performed with *HYD*.

The features described in Chapter 2 use only the input records described in Chapter 2. The features covered in the other chapters require a job control *JC* record, described in Chapter 7, at the beginning of the *HIN* file followed by other optional input records described in Chapters 7 and 8. The methods of Chapter 2 require a *HS* record rather than the *JC* record of Chapters 3-8.

A *JC* record placed at the beginning of the *HIN* file contains parameters that select the other files to be activated (opened). The second column of Table 1.1 shows the *JC* record parameter or other input that activates each of the files. The main *HYD* input *HIN* file contains the records controlling the operations performed by *HYD*. With job control *JC* record *JC(1)* and *JC(2)* options 1 and 2, *FLO* and *EVA* input files have the same format in either *HYD* or *SIM*. Input file types *DIS* and *DSS* also have the same format in either *HYD* or *SIM*. The *HYD* *root1.OUT* input file is the *SIM* output *OUT* file without any modification. The *HS* record of Chapter 2 provides additional flexibility for the user to select filename extensions (*TSF*, *FLO*, *EVA*, *DSS*) for time series input and output files containing essentially any monthly time series variable.

Table 1.1  
*HYD* Input and Output Files

Filename	Activation	Contents
<u><i>HYD</i> Input Files</u>		
root1.HIN	always required	All input not contained in other input files.
root1.DSS	JC(1)=6, JC(2)= 6, <i>HS</i> record	Time series input data in DSS format.
root1.FLO	JC(1) = 1, 2, 5 or JC(3)=2, 3, 4	Inflow <i>IN</i> records with stream inflows.
root1.EVA	JC(2) = 1, 2, or 5	<i>EV</i> records with evaporation-precip depths.
root1.HYD	JC(1) = 3, 4 or JC(2) = 3, 4	<i>IN</i> and <i>EV</i> records in a single file.
root1.DIS	JC(7) = 1	Flow distribution <i>FD</i> , <i>FC</i> , and <i>WP</i> records.
root1.OUT	JC(1)=7, JC(2)=7, or JC(6)=1,2 or one or more <i>OI</i> records	<i>SIM</i> simulation results output OUT file.
root1.TSF	<i>HS</i> record INEXT (Table 2.1)	Monthly times series for any variable.
Precipitation.PPP	<i>HS</i> (Table 2.1), <i>FE</i> or <i>EE</i> records	TWDB statewide precipitation dataset.
Evaporation.EEE	<i>HS</i> (Table 2.1), <i>FE</i> or <i>EE</i> records	TWDB statewide evaporation dataset.
PrecipEvap.DSS	<i>HS</i> (Table 2.1), <i>FE</i> or <i>EE</i> records	TWDB precipitation and evaporation data.
<u><i>HYD</i> Output Files</u>		
root2.HMS	always opened automatically	Traces and error and warning messages.
root2.FLO	JC(8) = 1, 2, <i>HS</i> record OUTEXT	Inflow <i>IN</i> records with stream inflows.
root2.EVA	JC(8) = 1, 2, <i>HS</i> record OUTEXT	<i>EV</i> records with evaporation-precip depths.
root2.TSF	<i>HS</i> record OUTEXT (Table 2.1)	Monthly times series for any variable.
root2.DSS	JC(8) = 6, <i>HS</i> record DSSFILE	Flows and evap-precip in DSS format.
root2.HOT	<i>HS</i> record STAT (Table 2.1) JC(8) = 3, 4 or JC(9) = 3, 4, 7 JC(1) = 1, 2, 3 or JC(1) = 1 NEGINC = 2, 3 on <i>JC</i> record One or more <i>OI</i> records FE(1) = 1,2,3,4,5 on <i>FE</i> record	Statistical analysis results (Chapter 2) All output not contained in other output files (Chapters 3 through 8.).

Output file types are also listed in Table 1.1. Root2.FLO, root2.EVA, and root2.DSS files are created by *HYD*, in most cases, to serve as input files for *SIM*. The river flow and evaporation-precipitation data may also be stored in columnar format in a root2.HOT file for transport to Microsoft Excel or other programs. Other information that may be stored in a HOT file is described throughout the remaining chapters of this manual.

The PrecipEvap.DSS, Precipitation.PPP and Evaporation.EEE files created from the statewide database maintained by the TWDB and a DSS version of these files are described in Chapter 2 and applied in Chapters 2, 5 and 6. These files containing TWDB monthly evaporation and precipitation data for 168 quadrangles are available with the WRAP software and manuals.

The *HYD* message HMS file is similar to the *SIM* message MSS file. *HYD* contains a system of traces and error and warning messages written to the message HMS file that is similar to *SIM*. Features for detecting errors in data files are covered by Chapter 9 of the *Reference Manual*.

## CHAPTER 2

### COMPILATION AND ANALYSIS OF HYDROLOGIC TIME SERIES DATA

Chapter 2 documents the subprogram *HydSeries* (*Hydrologic Series*) component of *HYD* and explores relevant time series data. The focus is on time series of monthly precipitation, evaporation, and net evaporation-precipitation depths in inches or feet per month and monthly stream flow volumes in acre-feet/month or mean flow rates in cfs, but the data compilation and analysis tools are applicable to essentially any time series variables and any measurement units. Chapter 2 is self-contained with relevant input record descriptions found within the chapter.

The methods presented in Chapters 3 through 8 focus on creating or updating *SIM* input *IN* records of monthly naturalized river flow volumes and *EV* records of monthly reservoir net evaporation less precipitation rates in either text file or DSS file format. Chapter 2 covers general time series data management and analysis capabilities that can be used either in combination with the methods presented of Chapters 3 through 8 or independently thereof.

The programs *HYD*, *SIM*, *SIMD*, *TABLES*, and *HEC-DSSVue* are components of a WRAP data management and analysis system that can be employed individually or in combination to perform various tasks. The WRAP program *HYD* reads and creates both DSS and text files. *HEC-DSSVue* provides flexible capabilities for plotting time series and performing statistical and other analyses of data read from a DSS file created by *HYD* or other WRAP programs. The WRAP program *TABLES* includes flexible statistical frequency analysis capabilities. *TABLES* can read essentially any time series dataset from any DSS file including those created by *HYD*. Program *HYD* can read DSS and text files created by *HEC-DSSVue* or *TABLES*. *HYD* includes statistical trend analysis routines described later in this chapter.

#### ***HYD Subprogram HydSeries***

The *HydSeries* feature of *HYD* provides options for performing the following tasks related to compiling, managing, converting file formats, and analyzing time series data.

- Read sequences of monthly time series data in the following alternative formats.
  1. *SIM* hydrology FLO or EVA file input record format grouped by year.
  2. *SIM* hydrology FLO or EVA file input record format grouped by location.
  3. Columnar table format with time series tabulated in columns.
  4. DSS file in *SIM* hydrology input record DSS format.
  5. TWDB quadrangle monthly precipitation and evaporation file PrecipEvap.DSS.
  6. TWDB quadrangle datasets in files Precipitation.PPP and Evaporation.EEE.
- Store the time series data in a DSS file or text file in alternative *SIM* input record formats.
- Store the time series data and other computed quantities in various table formats.
- Develop annual series of totals, means, or minima/maxima of monthly moving averages.
- Compute basic statistics for the monthly and annual data.
- Perform linear trend regression analyses of monthly or annual time series.

*HydSeries* can be used to convert time series datasets between DSS and text file formats. *HEC-DSSVue* can be employed to read time series data stored by *HydSeries* in a DSS file and prepare plots and perform statistical analyses and other data management and analysis operations. Frequency analyses of data series created with *HydSeries* can also be performed with *TABLES*.

Annual series derived with *HydSeries* from monthly input include annual totals or means or annual minima or maxima of monthly moving averages. Statistics tables include means, standard deviations, and ranges of monthly and annual quantities. Linear regression trend analysis is performed for the original monthly time series or derived annual series.

### Time Series Input and Output Files

Subprogram *HydSeries* reads *HS*, *SI*, *\*\**, and *ED* records from the *HYD* input HIN file. These are the only input records other than the time series datasets discussed below. Statistical analysis results are recorded in the general-purpose *HYD* output file with filename extension HOT. Trace messages and error and warning messages are recorded in the message HMS file.

Input entries INFILE and OUTFILE in *HS* record fields 4 and 5 specify the file and record format for monthly time series input and output files. Filename extensions for the input and output files are specified in *HS* record fields 6 and 7 as the three-character input variables INEXT and OUTEXT. Possible INEXT and OUTEXT filename extensions include FLO, EVA, TSF, HIN, and HOT. For example, with FLO entered for INEXT and OUTEXT, time series data are read from a file with filename root.FLO and output to a file with filename rootOUT.FLO.

Two-character record identifiers can be assigned by INID and OUTID in *HS* record fields 8 and 9. Common examples include *IN* and *EV*, but any other record identifiers can also be used.

The *HS* record INFILE and OUTFILE options controlling reading the initial monthly time series dataset and recording the optionally modified monthly dataset are as follows.

1. Monthly data for any time series variable may be read from and/or written to text files with filename extensions FLO, EVA, TSF, HIN, HOT specified by INEXT and OUTEXT (*HS* record fields 4 and 5) with the data in standard *SIM* input record format grouped by years.
2. Likewise, data may be read from and written to text files with filename extensions specified by INEXT and OUTEXT with the data in *SIM* input record format grouped by control points.
3. Monthly data for any time series variable may be read from a file with filename extension INEXT (HIN, TSF, FLO, EVA) or read by a file with filename extension OUTEXT (HOT, TSF, FLO, EVA) with the data tabulated in columns with one column for each time series.
4. Monthly data for any time series variable may be read from or written to a DSS input file with filename root.DSS or rootOUT.DSS with data in standard *SIM* input DSS record format.
5. Monthly precipitation and/or evaporation data for 92, 168, or selected quadrangles may be read from a DSS file distributed with WRAP, with filename PrecipEvap.DSS, containing the statewide databases maintained by the Texas Water Development Board (TWDB). This file may be created by reading the files with filenames Precipitation.PPP and Evaporation.EEE (INFILE option 6) and recording the data in the file PrecipEvap.DSS (OUTFILE option 5).
6. Monthly precipitation or evaporation data for 92 quadrangles covering Texas, 168 quadrangles in the database, or selected quadrangles may be read from text files distributed with WRAP with filenames Precipitation.PPP and Evaporation.EEE containing the statewide databases maintained by the Texas Water Development Board (TWDB). These files were created as discussed later in this chapter and are distributed with WRAP.

*HS* record INFILE options 1, 2, 3 allow the input data to be stored in a text file with user-specified filename in different optional alternative input record formats. INFILE options 1 and 2 are equivalent to *SIM JO* record field 2 INEV options 1 and 2 covered in the *Users Manual* [2] and *HYD JC* record JC(1) options 1 and 2 covered in Chapter 7 of this *Hydrology Manual*. INFILE options 4 and 5 access DSS files. Option 5 is equivalent to *SIM JO* record INEV option 6 and *HYD JC* record JC(1) option 6. INFILE options 5 and 6 use existing text files of TWDB databases provided with the WRAP software and discussed later in this chapter.

*IN* and *EV* records from *SIM* input FLO or EVA files are read by *HYD* with INFILE options 1 or 2. OUTFILE options 1 and 2 can be used to create a *SIM* input FLO or EVA file. *HydSeries* INFILE and OUTFILE option 4 and *SIM* INEV option 6 allow *HYD* and *SIM* to work with the same DSS file. The standard format of *SIM IN* and *EV* records used with *HydSeries* INID and OUTID records is described in Chapter 7 of this manual and Chapter 3 of the *Users Manual* [2]. The INFILE and OUTFILE option 3 tabular format is illustrated later in Table 2.9.

All INFILE options read only monthly time series data. OUTFILE options 1 and 2 output only monthly time series data. OUTFILE options 3, 4, and 5 write either monthly time series (SERIES option 1) or annual time series (SERIES options 2, 3, 4, and 5) to the output file. STATS option 4 creates tables of monthly and annual time series in other formats.

The user assigns the roots for the input (root1) and output (root2) filenames during the login procedure that may be managed through the *WinWRAP* interface. The root (*root2*) selected for the filenames of the output files may be different than the input file root (*root1*). If the user chooses to not enter root2, the default automatically adopted by *HYD* is to create root2 by appending the phrase *OUT* to root1. Thus, the default filename root for root2 is root1OUT. For example, with the default TSF for entered in *HS* record fields 4 and 5 for INFILE and OUTFILE, if the filename root *Example* is entered for input files but the filename root for output files is left blank in the *WINWRAP* login, the TSF input file and TSF output file will have the filenames *Example.TSF* and *ExampleOUT.TSF*.

Datasets of monthly time series data are converted from one format to another by selecting an OUTFILE output option that is different from the INFILE input option. *HydSeries* may be employed simply to change the format and organization of monthly time series datasets. *HydSeries* also provides capabilities for creating annual time series from monthly series and performing statistical analyses, including linear regression trend analysis as well as computing basic statistics for the monthly and/or annual time series. Convenient access to the TWDB precipitation and evaporation database (INFILE options 5 and 6) is also provided.

### *HYD Input HIN File Records*

The WRAP program *HYD* subprogram *HydSeries* is independent of the *HYD* features covered in Chapters 3 through 8 from the following perspectives. Chapter 2 is self-contained in that the relevant *HYD* input HIN file input record descriptions (*HS* and *SI* records) are included as Tables 2.1 and 2.2 along with the explanations of methods presented throughout the chapter. Similar tables describing the more numerous input records used to apply the methods covered in Chapters 3 and 4 and Chapters 5 and 6 are found in the separate Chapters 7 and 8. When *HydSeries* is applied, *HYD* is normally executed with the HIN input file containing only the *HydSeries* input records described in Chapter 2.

Table 2.1  
HS Record in HIN File

field	columns	variable	format	value	description
1	1-2	CD	A2	HS	Record identifier.
2	3-8	YRBEG	I6	+	Beginning year of data series.
3	9-16	YREND	I8	+	Ending year of data series.
<u>Time Series Input File and Format</u>					
4	20	INFILE	I4	1	INEXT file in <i>SIM</i> input format grouped by year.
				2	INEXT file in <i>SIM</i> input format grouped by location.
				3	INEXT file table with columns for each time series.
				4	DSS file root.DSS in <i>SIM</i> input record format.
				5	File PrecipEvap.DSS with PPP and EEE file data.
				6	Files Precipitation.PPP and Evaporation.EEE.
<u>Time Series Output File and Format</u>					
5	24	OUTFILE	I4	blank, 0	The time series data is not recorded in an output file.
				1	OUTEXT file in <i>SIM</i> input format grouped by year.
				2	OUTEXT file <i>SIM</i> input format grouped by location.
				3	OUTEXT file table with columns for each time series
				4	DSS file root.DSS in <i>SIM</i> input record format.
				5	DSS file with data from PPP and EEE files.
<u>Time Series Filename Extensions</u>					
6	26-28	INEXT	1x,A3	AN	Filename extension for the time series input file.
7	30-32	OUTEXT	1x,A3	AN	Filename extension for the time series output file.
<u>Time Series Input and Output Record Identifiers</u>					
8	35-36	INID	2x,A2	AN	Input record identifier. Default is no identifier.
9	39-40	OUTID	2x,A2	AN	Output record identifier. Default is no identifier.
<u>PE Options for INFILE Options 5 and 6</u>					
10	44	PE	I4	1	Net evaporation–precipitation depths in inches.
				2	Evaporation depths in inches from EEE or DSS file
				3	Precipitation depths in inches from PPP or DSS file.
11	48	SSI	I4	blank, 0	Identifiers are provided on <i>SI</i> records for PE = 1-3.
				92	92 quads encompassing Texas for PE options 1-3.
				168	All 168 quads used with PE options 1 through 3.
<u>Statistical Analysis with Results in HOT File</u>					
12	52	STAT	I4	blank, 0	The statistical analysis options are not employed..
				1	Mean, standard deviation, minimum, and maximum.
				2	Linear regression trend analysis for each time series.
				3	Means for each of 12 months and annual mean.
				4	Monthly or annual time series tabulations.
<u>Time Series to be Analyzed and/or Output</u>					
13	56	SERIES	I4	blank,0,1	Monthly series of quantities.
				2, 3	Annual series of monthly totals or means.
				4, 5	Annual minima or maxima of moving averages.
14	60	MA	I4	+	Months for moving average. Default is one month.
15	61-68	MX	F8.0	F8.0	Multiplier or unit conversion factor. Default is 1.0.

Table 2.1 Continued  
*HS* Record in HIN File

field	columns	variable	format	value	description
<i>Optional DSS Parameters with Defaults</i>					
16	72	DSSMES	I4	blank, 0, 2 +	Default DSS trace, error, and warning messages. Alternative levels ( <i>Reference &amp; Users Manuals</i> ).
17	73-76	DSSMON	1x,A3	AN	First month (JAN, FEB, ... , DEC). Default = JAN
18	77-92	DSSAIN	A16	AN	Part A of DSS pathnames for input and output file, respectively. The default is the DSS filename root.
19	93-108	DSSAOUT	A16	AN	

Table 2.2  
Time Series Identifiers *SI* and End-of-Data *ED* Records in the HIN File

field	columns	variable	format	value	description
1	1-2	CD	A2	SI	Record identifier. Series or site identifier record.
2	3-8	NID	I6	+	Total number of identifiers on the <i>SI</i> records.
3	9-104	TSID(I)	12A8	AN	Time series identifiers. Up to 12 per <i>SI</i> record.
field	columns	variable	format	value	description
1	1-2	CD	A2	ED	Record identifier. Last record read by computer.

When used with subprogram *HydSeries*, the *HYD* input HIN file always includes a hydrologic series *HS* record (Table 2.1) and end-of-data *ED* record (Table 2.2). Site identifier *SI* records (Table 2.2) with identifiers for each time series are included in the HIN file if needed. The contents and format of each field of the *HS* and *SI* records are outlined in Tables 2.1 and 2.2.

The optional set of one or more *SI* records follows after the required single *HS* record. Any number of optional comment *\*\** records may also be included anyplace in the HIN file or the time series input files. The *ED* record is the last record in the HIN file read by the computer. Any records stored in the file after the *ED* record are not read by the computer.

#### Explanation of *HS* Record Fields

*Fields 2 and 3:* The period-of-analysis extending from year YRBEG through year YREND may be all or a sub-period of the time period covered by the continuous monthly data series stored in the time series input file. There can be no gaps of months with missing data.

*Fields 4, 5, 6, and 7:* INFILE and OUTFILE specify the organization of the input and output files from and to which time series quantities are read and written as described on pages 10-11. User-specified input and output filename extensions INEXT and OUTEXT entered in *HS* record fields 6 and 7 are used with INFILE and OUTFILE options 1, 2, and 3. INEXT can be FLO,

EVA, HIN, or TSF, with a default of TSF (time series file). OUTEXT can be FLO, EVA, HOT, or TSF, with a default of TSF. Any of these filename extensions can be used with any time series variable. The alternative choices simply allow user flexibility in labeling files.

FLO and EVA are conventional filename extensions used for files of naturalized stream flows (*IN* records) and net evaporation-precipitation rates (*EV* records) in *SIM* input datasets. Time series data can also optionally be read from a HIN file following the *HS* and *SI* records and before the *ED* record. Time series can be output to the HOT file. The extension TSF is the default option for input and output files with INFILE and OUTFILE options 1, 2, or 3 selected.

INFILE and OUTFILE options 4 and 5 are DSS files with input and output filenames root1.DSS, root2.DSS or root1OUT.DSS, PrecipEvap.DSS, and PrecipEvapOUT.DSS. INFILE option 6 reads the files Precipitation.PPP and Evaporation.EEE that are already-created text files of TWDB databases distributed with WRAP that are discussed later in this chapter. The DSS input file with filename PrecipEvap.DSS file was created from the PPP and EEE text files.

Fields 8 and 9: Time series identifiers such as *IN*, *EV*, or any other 2-character identifier can be assigned as the first two characters of text file input or output records for INFILE/OUTFILE options 1 and 2 or pathname part C of the DSS input or output records for INFILE/OUTFILE option 4. With fields 8 and/or 9 blank, no identifier is assigned. Like filename extensions, the INID and OUTID record identifiers are only labels and have no effect on *HydSeries* operations.

Fields 10 and 11: PE options 1, 2, or 3 are specified in *HS* record field 10 if and only if INFILE option 5 or 6 is specified in *HS* record field 4. The PE options manage the TWDB quadrangle precipitation and evaporation datasets discussed later in this chapter. If *HS* record field 11 is blank (SSI=0), selected quadrangle identifiers are read from one or more *SI* records. SSI of 92 or 168 adopts the 92 quadrangle covering Texas or all 168 quadrangles in the TWDB database.

Field 12: Statistical analysis options activated by STAT in *HS* record field 12 are introduced on pages 16-17 and illustrated by Tables 2.5-2.8 and 2.12-2.20. Results are recorded in the HOT file. STAT option 1 creates a table showing the mean, standard deviation, minimum, and maximum for each time series. Option 2 applies linear regression for each time series. Option 3 computes an overall annual mean and 12 monthly means for the entire dataset. STATS option 4 creates a HOT file table of monthly data for SERIES=1 with a row for each time series and 12 columns of monthly values and an annual total column. Annual quantities are tabulated for SERIES options 2, 3, 4, and 5. The STATS option 4 annual table includes the annual quantity and minimum and maximum monthly amounts each year with dates.

Fields 13 and 14: *HydSeries* can write time series to an output file and/or perform statistical analyses with the monthly time series data read from an input file or the annual series computed as specified by SERIES in *HS* record field 13. Input parameter SERIES is applicable for any time series variable. The data series consist of either the (1) original monthly quantities, (2) annual totals, (3) annual means of monthly quantities, (4) annual minima of monthly quantities or minima of moving averages, or (5) annual maxima of monthly quantities or moving averages.

The default SERIES option 1 adopts the original monthly data. Option 2 creates an annual series by summing monthly quantities. Option 3 creates an annual series by averaging the 12 monthly

quantities for each year. Option 2 is normally selected to add monthly depths in inches or volumes in acre-feet to obtain annual depths or volumes. Option 3 is applicable for averaging mean monthly flow rates in cubic feet/second (cfs) to obtain mean annual rates in cfs.

Forward moving averages for MA months (*HS* record field 14) are computed for *SERIES* options 4 and 5. The MA months include the current month and next MA-1 future months. The default MA of only one month adopts the minimum or maximum monthly quantity in each year.

*Field 15:* The time series quantities are multiplied by *MX* entered in *HS* record field 15. The multiplier *MX* can be used as a unit conversion factor. *MX* has a default of 1.0.

*Fields 16:* The system of error and warning checks is similar in all of the *WRAP* programs as explained in Chapter 9 of the *Reference Manual* [1]. *HS* record field 16 *DSSM* options are identical to *SIM OF* record *DSS(6)* options for setting levels of trace and error messages for reading from and writing to *DSS* files, which are described in Chapter 3 of the *Users Manual* [2].

*Fields 17, 18, and 19:* Time series are dated on *DSS* records with January (*JAN*) being the default starting month (field 17). Otherwise, the 12 months in each year are identified by the integers 1 through 12. *HS* record fields 18 and 19 allow user-assigned labels for *DSS* pathname part A for the *DSS* input (*DSSIN*) and output (*DSSOUT*) files. These options provide additional flexibility in labeling groups of records stored in a *DSS* file for convenient identification. If field 18 and/or field 19 are left blank, the filename root is assigned to *DSS* record pathname part A.

#### *Time Series Site Identifier SI Records in the HIN File*

The *HydSeries* component of *HYD* can be employed with essentially any time series variable. Any number of time series may be processed in a single execution of *HYD*. Each data series has an identifier of up to six characters in length. The identifiers may be the six-character control point identifiers used in the *SIM* simulation model, the four-integer identifiers for quadrangles listed later in Table 2.3 with locations shown in Figure 2.1, or any other labels. Any number of *SI* records can be inserted in the *HIN* file after the *HS* record. Any number of time series identifiers can be listed on any number of *SI* records, with any number up to 12 identifiers on each *SI* record. The total number *NID* of identifiers [*TSID(I)*, *I*=1,*NID*] to be read from the one or more *SI* records is specified in the second field of the first *SI* record.

*SI* records are used only if control point, quadrangle, or other identifiers read automatically with the time series quantities are not sufficient to serve the purposes noted below. Identifiers are automatically read along with the time series quantities for *INFILE* options 1, 2, 3, 5, and 6. *SI* records are used if and only if the following data management tasks are performed.

1. *SI* records are required if time series are read from a *DSS* file pursuant to *INFILE* option 4. The *DSS* file may contain any number of time series. Only the time series with *DSS* record pathname part B identifiers listed on *SI* records are read.
2. The original input data series identifiers are also used for the corresponding output data series. By default, time series are recorded in the *OUTFILE* output file for all identifiers assigned to the *INFILE* input file time series. With *SI* records, the output is limited to the subset of only time series with identifiers included on *SI* records.

## **Statistical Analyses**

A time series dataset may contain any number of monthly or annual time series, with each series containing quantities for either each month or each year of the period-of-analysis. Statistical analyses are activated by input parameter STAT in *HS* record field 12. Results are recorded in the *HYD* output *HOT* file. The *HS* record field 12 STAT options are as follows.

- Option 1: A table is created in the *HOT* file that contains the mean, standard deviation, minimum, and maximum for each individual time series included in the dataset.
- Option 2: Regression analysis computations are performed as described in the next section.
- Option 3: The 12 monthly means and annual mean for the entire dataset of monthly quantities.
- Option 4: A table for monthly data has a row for each time series and 12 columns of monthly values and an annual total column. The table for annual series includes for each year the annual quantity and minimum and maximum monthly amounts with dates.

*HEC-DSSVue* and *TABLES* compute basic statistics and perform statistical frequency analyses for sets of daily, monthly, or annual data. *HEC-DSSVue* and *TABLES* also include various options for manipulating time series datasets and then computing basic statistics and performing frequency analyses of the resulting adjusted datasets. *HEC-DSSVue* includes options for plotting frequency curves as well as time series graphs. Statistical analyses are discussed throughout the *Reference*, *Users*, *Fundamentals*, and *Daily Manuals*. Chapter 9 of the *Daily Manual* provides an overview summary of WRAP statistical frequency analysis capabilities.

Datasets created with *HYD* and stored in DSS output files are conveniently accessible to *TABLES* and/or *HEC-DSSVue* for further analyses and vice versa. The *HydSeries* component of *HYD* provides trend analysis capabilities described below based on standard textbook least-squares linear regression designed to support compilation and analysis of hydrology datasets.

### **HydSeries Statistical Regression Trend Analysis**

Stationarity refers to constant conditions (homogeneity) over time. Population growth and associated increased water use, construction of dams and other water resources development facilities, land use changes, and climatic changes can result in non-stationarities (long-term modifications) in characteristics of precipitation, evaporation, stream flow, and other hydrologic variables. Time series plots developed with *HEC-DSSVue* are very useful in exploring trends and long-term changes. *HEC-DSSVue* also includes least-squares linear regression trend analysis computations. The *HydSeries* statistical trend analysis methods discussed here are also designed to detect and analyze long-term changes (non-stationarity) or lack thereof (stationarity).

The standard least-squares linear regression methodology based on the following equations explained in many statistics and numerical methods textbooks is applied in *HydSeries*.

$$E(Y|x) = a + bx \quad (2.1)$$

$$b = \frac{n \sum x_i y_i - (\sum x_i)(\sum y_i)}{n \sum x_i^2 - (\sum x_i)^2} \quad (2.2)$$

$$a = \bar{y} - b \bar{x} \quad (2.3)$$

$E(Y|x)$  denotes the conditional expectation of  $Y$  given  $x$ , and  $\bar{y}$  and  $\bar{x}$  are the means of  $y$  and  $x$ . The coefficients  $a$  and  $b$  in Equation 2.1 represent the  $y$ -intercept and slope of a straight line plot.

Regression is applied in many fields with many different paired variables. Linear and nonlinear regression are applied as described in Chapter 8 of the *Reference Manual* [1] to relate naturalized flows ( $Y$ ) to storage contents ( $X$ ) in conditional reliability modeling. Regression is employed as explained in Appendix A of the *Daily Manual* [5] to relate stream flows ( $Y$  and  $X$ ) at two different control points, lag ( $Y$ ) to flow ( $X$ ), and trend analysis of flow ( $Y$ ) as a function of time in days ( $X$ ). *HydSeries* uses linear regression to relate time series quantities ( $Y$ ) to time ( $X$ ) in months or years expressed as the consecutive integers 1, 2, 3, 4, 5, 6, etc.

Standard least-squares linear regression is activated by STAT option 2 in *HS* record field 12. Regression of a time series variable with time is commonly called trend analysis. The regression slope is an indicator of trends over time. Regression analysis may be performed for the data series defined by input parameter SERIES (*HS* record field 13), which consists of either the monthly quantities, aggregated annual quantities, annual minima of moving averages, or annual maxima of moving averages. The *HS* record field 12 STAT option 2 regression coefficient table created in the HOT file contains a line for each time series and the following columns as illustrated later by Tables 2.5, 2.6, 2.14, 2.18, 2.19, and 2.20.

- For PE options 1, 2, 3, the identifier in the first column of the table is the three or four digit integer quadrangle identifier assigned by the TWDB. For the default SSI option 0 (blank *HS* field 11), the site identifier is the control point or site identifier from the *SI* records.
- The means of the quantities defined by PE and SERIES in the second column of Tables 2.5 and 2.6 are in units of inches/month for PE options 1, 2, and 3 with MX (*HS* record field 15) default of 1.0. Regression analysis can be performed for any variable in any units.
- Columns 3 and 4 contain the  $y$  intercept ( $a$ ) and slope ( $b$ ) in Equation 2.1 where  $Y$  is the time series variable and  $X$  is the month or year expressed as 1, 2, 3, 4, 5, etc. The regression provides an indication of long-term trends or changes. A slope of zero and intercept equal to the mean indicates that there is no long-term linear trend.

With MX default of 1.0, for SERIES option 1, the  $Y$  in the regression equation is the monthly time series quantity such as stream flow, precipitation (PE=3), or evaporation (PE=2).

With MX=1.0, for SERIES option 2 or 3, the  $Y$  in the regression equation is the annual time series quantity aggregated by *HydSeries* by summing or averaging monthly values.

For SERIES options 4 and 5, the  $Y$  in the regression equation is the minimum (option 4) or maximum (option 5) of the MA-month moving average of the monthly time series values.

- Column 5 of the table contains the intercept from column 3 expressed as a percentage of the mean in column 2.
- Column 6 of the table contains the slope from column 4 expressed as a percentage of the mean in column 2.
- Column 7 of the table contains the mean from column 2 expressed as a percentage of the statewide mean in column 2 of the bottom line (labeled *Total*) of the table. Column 7 is included only for the PE options (PE = 1, 2, or 3 in *HS* record field 10).

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

WRAP applications of DSS files and *HEC-DSSVue* are outlined in Chapter 6 of the *WRAP Users Manual* [2]. Data storage system (DSS) routines created by the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) are incorporated in the WRAP programs, including *HYD*, during compilation allowing creation and access to DSS files used for storing and managing time series of *SIM* and *SIMD* simulation input hydrology data and simulation results. DSS and *HEC-DSSVue* can be used with WRAP in many different ways.

DSS files can also be created and/or accessed with the DSS interface program *HEC-DSSVue* which provides extensive capabilities for plotting time series graphs, statistical analyses, mathematical computations, data adjustments, and data cataloging/searching/displaying/checking operations. *HEC-DSSVue* is documented in detail by a user's manual [8] available at the HEC website along with the *HEC-DSSVue* software (<http://www.hec.usace.army.mil/>).

DSS files always have the filename extension DSS. A companion DSS record catalog file with filename extension DSC is automatically created by DSS software.

### **Use of DSS Files and HEC-DSSVue with HYD**

*HYD* includes options that read a DSS input file and/or create a DSS output file. DSS input and output files for *HYD* are controlled by HIN file input parameters on the *HS* record described in this chapter and *JC* record described in Chapter 7. *HYD* and the other WRAP programs include options for using either DSS files or text files for time series input and output, which provides significantly greater flexibility but adds the complexity of more user choices. Both *HYD* and *TABLES* include features for conveniently converting datasets between text and DSS files. Text files are always used for input and output data other than time series.

HEC-DSS references data records by their pathnames, which consist of six parts in the format /A/B/C/D/E/F/. The pathnames for input and output records are assigned automatically by the WRAP programs, with some flexibility for user deviation from default conventions. DSS records can be easily renamed within the *HEC-DSSVue* editor. Pathname parts are assigned similarly in *HYD*, *SIM*, *SIMD*, and *TABLES*, with minor differences as necessary to accommodate the different programs. Conventional *HYD* and *SIM* pathname parts for hydrology input records are defined in Table 3.4 of Chapter 3 of this manual. The parts of the pathnames for the data records stored in *HydSeries* input and output DSS files are assigned as follows.

- Part A – Filename root of the *HYD* input and output files unless otherwise specified by DSSIN and/or DSSOUT in *HS* record fields 18 and 19.
- Part B – *SI* record TSID(I), control point, quad number, or other identifier for the time series.
- Part C – INID and OUTID in *HS* record fields 8 and 9 for PE=0 in *HS* field 10 is typically *IN* or *EV* but can be any two-character label. Part C is set by *HYD* for PE options 1-6.
- Part D – Date of the beginning of the time series such as 01JAN1940.
- Part E – 1MON or 1YEAR for monthly or annual time interval.
- Part F – Part F is blank (not used) for the *HYD* root.DSS input file. Descriptive labels are automatically assigned by *HYD* as appropriate for the output DSS file.

Pathname parts for records in *HYD* DSS input files must conform to *HYD* conventions. *HYD* output is automatically assigned pathname parts. Pathnames can be easily changed in the *HEC-DSSVue* editor [2, 8]. DSS provides flexibility in naming records but has certain requirements. Part E must be 1DAY, 1MON, 1YEAR, or other indicator of time interval, and Part D is always used to define the time range covered by the data [2, 8].

*HEC-DSSVue* includes data types and units that are primarily for labeling but can affect certain computational options available within *HEC-DSSVue* [2, 8]. Assigned data types and units are easily changed in the *HEC-DSSVue* editor. The DSS conventions adopted in *HydSeries* for data type and units are as follows. The adopted type is "PER-CUM", meaning cumulative during period. Default units are inches (PE=1-3) or feet (PE=1-3 and MX=0.083333) for precipitation and evaporation depths and acre-feet for all other variables. The data type and units do not affect computations performed within *HYD* and can be easily changed within *HEC-DSSVue*.

### **TWDB Precipitation and Evaporation Datasets**

The Texas Water Development Board (TWDB) maintains datasets of observed monthly precipitation depths and monthly reservoir surface evaporation depths for a grid of one-degree quadrangles covering Texas. The precipitation data date back to January 1940. The dataset of evaporation depths begins in January 1954. The TWDB updates the datasets each year about May to add data for January through December of the preceding year. The TWDB datasets of monthly precipitation depths and reservoir surface evaporation depths in inches and explanation of methods employed in compiling the data are available at the following TWDB websites.

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

<http://www.twdb.texas.gov/surfacewater/conditions/evaporation/evapinfo/index.asp>

A total of 168 one-degree quadrangles covering an area extending 12 degrees longitude and 14 degrees latitude encompass adjacent surrounding land area along with Texas. Complete series of monthly precipitation and evaporation data are available for the 92 one-degree quadrangles shown in Figure 2.1 that encompass the state. The datasets include an additional 76 quadrangles located outside of Texas, but there are periods of missing data for these quadrangles. The 168 one-degree quadrangles define a grid with 12 rows and 14 columns. The three or four digit quadrangle identifiers consist of the row and column numbers. The areas of each quad, in square miles tabulated in Table 2.3 are incorporated in *HydSeries* for use in determining area-statewide averages. *HydSeries* computes the statewide average quantity each month as an area-weighted average of the evaporation or precipitation for each of the 92 quadrangles.

*HydSeries* includes features activated by *HS* record field 10 PE options for working with all data series simultaneously for either the 92 quadrangles encompassing Texas (Figure 2.1), all of the 168 quadrangles in the TWDB database, or user-selected quadrangles. Other *HYD* routines discussed in later chapters employ data series for user-selected quadrangles. Methods for converting precipitation and evaporation datasets to *SIM* input datasets of *EV* records are covered in Chapters 3 and 5. The naturalized flow synthesis model of Chapter 6 uses the TWDB precipitation and evaporation data sequences as input. *HYD* input records used to apply capabilities presented in Chapters 3, 5, and 6, including managing of precipitation, evaporation, and evaporation-precipitation depths, are described in Chapters 7 and 8.

The precipitation and evaporation datasets were obtained from the TWDB in conjunction with development and maintenance of the WRAP modeling system at Texas A&M University and stored as text files with the filenames Precipitation.PPP and Evaporation.EEE. The single DSS file PrecipEvap.DSS created with *HydSeries* contains the same TWDB data in DSS format. Access by the WRAP program *HYD* to these files is controlled by *HS* record input parameters INFILE and PE described earlier in this chapter and *EE* record parameter EE described later in Chapter 8. The two text files and single DSS file of monthly precipitation and evaporation in inches for the 168 quadrangles are distributed with the WRAP software and documentation.

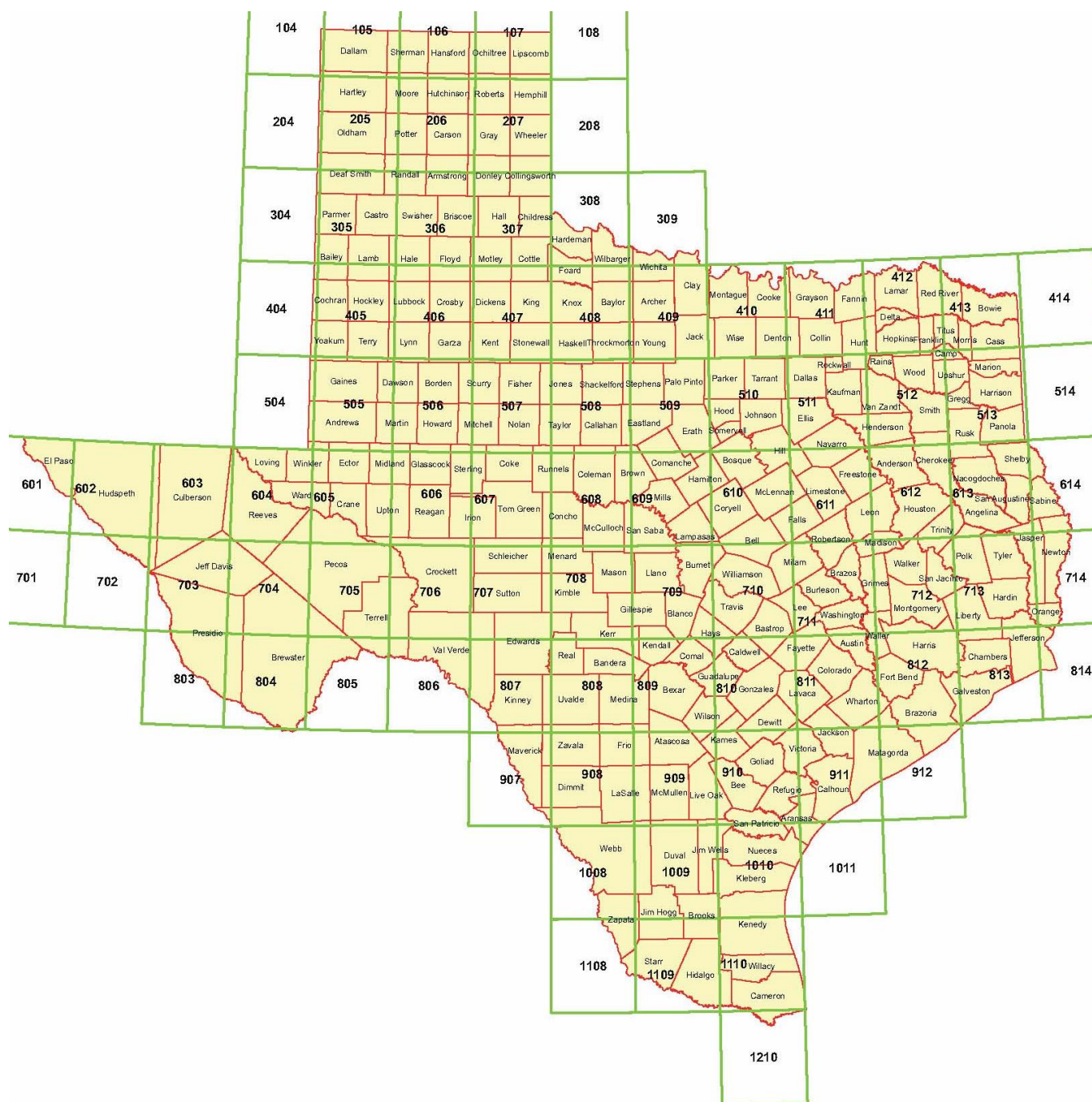


Figure 2.1 TWDB Quadrangle Map for Precipitation and Evaporation Data

Table 2.3  
Areas in Square Miles of 168 One-Degree Quadrangles

Quad ID	Area (sq miles)	Quad ID	Area (sq miles)	Quad ID	Area (sq miles)	Quad ID	Area (sq miles)
101	3,855.71	401	3,968.90	701	4,092.19	1001	4,226.81
102	3,855.71	402	3,968.78	702	4,092.19	1002	4,226.80
103	3,855.75	403	3,968.81	703	4,092.20	1003	4,226.81
104	3,855.77	404	3,968.79	704	4,092.17	1004	4,226.82
105	3,855.75	405	3,968.95	705	4,092.18	1005	4,226.83
106	3,855.68	406	3,968.89	706	4,092.14	1006	4,226.83
107	3,855.75	407	3,968.85	707	4,092.17	1007	4,226.83
108	3,855.74	408	3,968.84	708	4,092.14	1008	4,226.83
109	3,855.78	409	3,968.85	709	4,092.13	1009	4,226.81
110	3,855.70	410	3,968.84	710	4,092.16	1010	4,226.77
111	3,855.75	411	3,968.86	711	4,092.17	1011	4,226.82
112	3,855.70	412	3,968.87	712	4,092.16	1012	4,226.87
113	3,855.71	413	3,968.88	713	4,092.20	1013	4,226.87
114	3,855.71	414	3,968.77	714	4,092.22	1014	4,226.86
201	3,892.26	501	4,008.79	801	4,135.74	1101	4,274.40
202	3,892.31	502	4,008.76	802	4,135.72	1102	4,274.39
203	3,892.34	503	4,008.80	803	4,135.72	1103	4,274.40
204	3,892.34	504	4,008.80	804	4,135.74	1104	4,274.40
205	3,892.34	505	4,008.82	805	4,135.81	1105	4,274.40
206	3,892.38	506	4,008.75	806	4,135.74	1106	4,274.40
207	3,892.41	507	4,008.70	807	4,135.75	1107	4,274.39
208	3,892.37	508	4,008.73	808	4,135.77	1108	4,274.36
209	3,892.36	509	4,008.74	809	4,135.74	1109	4,274.39
210	3,892.31	510	4,008.76	810	4,135.70	1110	4,274.44
211	3,892.38	511	4,008.75	811	4,135.73	1111	4,274.46
212	3,892.46	512	4,008.70	812	4,135.77	1112	4,274.49
213	3,892.40	513	4,008.73	813	4,135.77	1113	4,274.48
214	3,892.36	514	4,008.75	814	4,135.71	1114	4,274.47
301	3,930.04	601	4,049.88	901	4,180.60	1201	4,323.42
302	3,929.98	602	4,049.88	902	4,180.60	1202	4,323.41
303	3,930.01	603	4,049.90	903	4,180.60	1203	4,323.41
304	3,930.01	604	4,049.91	904	4,180.62	1204	4,323.41
305	3,930.05	605	4,049.86	905	4,180.64	1205	4,323.41
306	3,930.06	606	4,049.82	906	4,180.62	1206	4,323.41
307	3,930.07	607	4,049.84	907	4,180.62	1207	4,323.41
308	3,930.02	608	4,049.90	908	4,180.60	1208	4,323.43
309	3,930.00	609	4,049.85	909	4,180.55	1209	4,323.46
310	3,930.00	610	4,049.88	910	4,180.53	1210	4,323.52
311	3,930.06	611	4,049.89	911	4,180.59	1211	4,323.55
312	3,930.13	612	4,049.87	912	4,180.64	1212	4,323.54
313	3,930.08	613	4,049.87	913	4,180.66	1213	4,323.53
314	3,930.06	614	4,049.87	914	4,180.65	1214	4,323.51

## Graphical Analysis of Precipitation and Evaporation Rates

Subprogram *HydSeries* of the WRAP program *HYD* generates time series datasets and statistical metrics for precipitation and evaporation rates in the same format for both individual quadrangles and statewide averages. The following presentation focuses on statewide averages. However, the same plots and metrics can be developed for each individual quadrangle. Similar plots and statistics can also be created for stream flow at a site or any other time series variable.

Examples of *HS* records that employ the TWDB evaporation and precipitation databases are shown in Table 2.4. Although a *HYD* input HIN file actually contains only one *HS* record, four variations of a *HS* record are included in Table 2.4 to illustrate different options. The first two *HS* records copy precipitation and evaporation depths in inches for the 92 quadrangles that encompass Texas from the *HYD* input files Precipitation.PPP and Evaporation.EEE to a DSS file. The third and fourth *HS* records convert the two monthly series of depths in inches/month to annual series of depths in inches/year and perform regression analyses on the two annual series. Alternative executions of *HYD* with the variations to the HIN file *HS* record shown in Table 2.4 and variations with other options selected along with *HEC-DSSVue* are employed to develop the time series plots and linear regression analysis metrics presented in this section.

Table 2.4  
Examples of *HS* Records

**	1					2					3					4					5													
**	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
HS	1	9	4	0					2	0	1	8		6		5						3		9	2									
HS	1	9	5	4					2	0	1	8		6		5						2		9	2									
HS	1	9	4	0					2	0	1	8		6		0						3		9	2		2							
HS	1	9	5	4					2	0	1	8		6		0						2		9	2		2							

These *HS* records generate 93 monthly and corresponding annual time series that include each of 92 quadrangles and statewide means. The plots of Figures 2.2-2.7 and linear regression statistics of Tables 2.5-2.7 are for the area-weighted average precipitation and evaporation depths over the 92 quadrangles delineated in Figure 2.1. The area-weighted averages are computed within *HYD* based on the areas tabulated in Table 2.3. The boundaries of Texas do not perfectly match the boundaries of the 92 quadrangles shown in Figure 2.1. However, the area-weighted average of a quantity for the 92 quadrangles is a close approximation of the average for the state of Texas. Thus, the quantities presented here are considered to be statewide averages.

Statewide averages of 1940-2018 monthly precipitation, 1954-2018 evaporation, and 1954-2018 net evaporation less precipitation in inches/month are plotted in Figures 2.2, 2.4, and 2.6. Annual totals (*HS* record field 13 SERIES option 2), minimum two-month average in each year (SERIES option 4), and maximum two-month average in each year (SERIES option 5) for precipitation, evaporation, and evaporation-precipitation in inches/month are plotted in Figures 2.3, 2.5, and 2.7. The annual series of minimum and maximum two-month averages are computed by *HYD* from two-month moving averages. The plots are created with *HEC-DSSVue* which reads the time series from a DSS file created with *HYD*. The results of multiple executions of *HYD* are stored in the same *HYD* DSS file read by *HEC-DSSVue* as an input file.

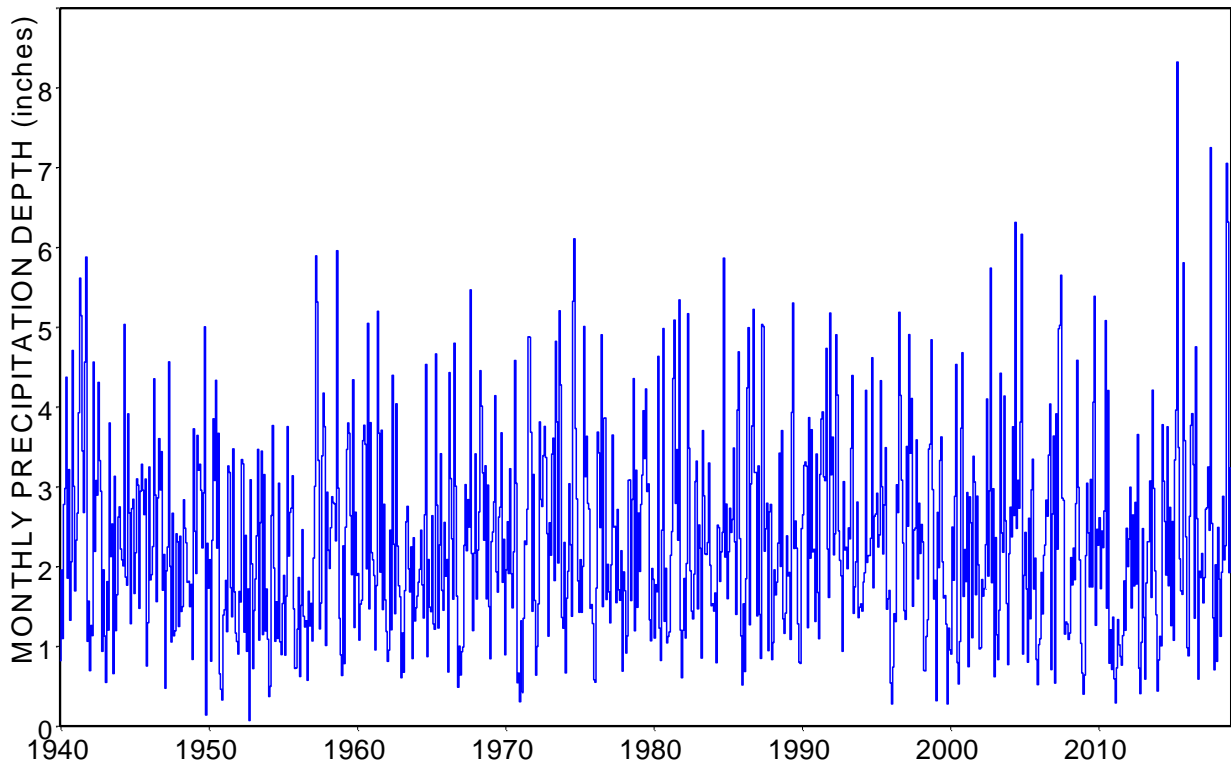


Figure 2.2 Statewide 92-Quad 1940-2018 Average of Monthly Precipitation in inches

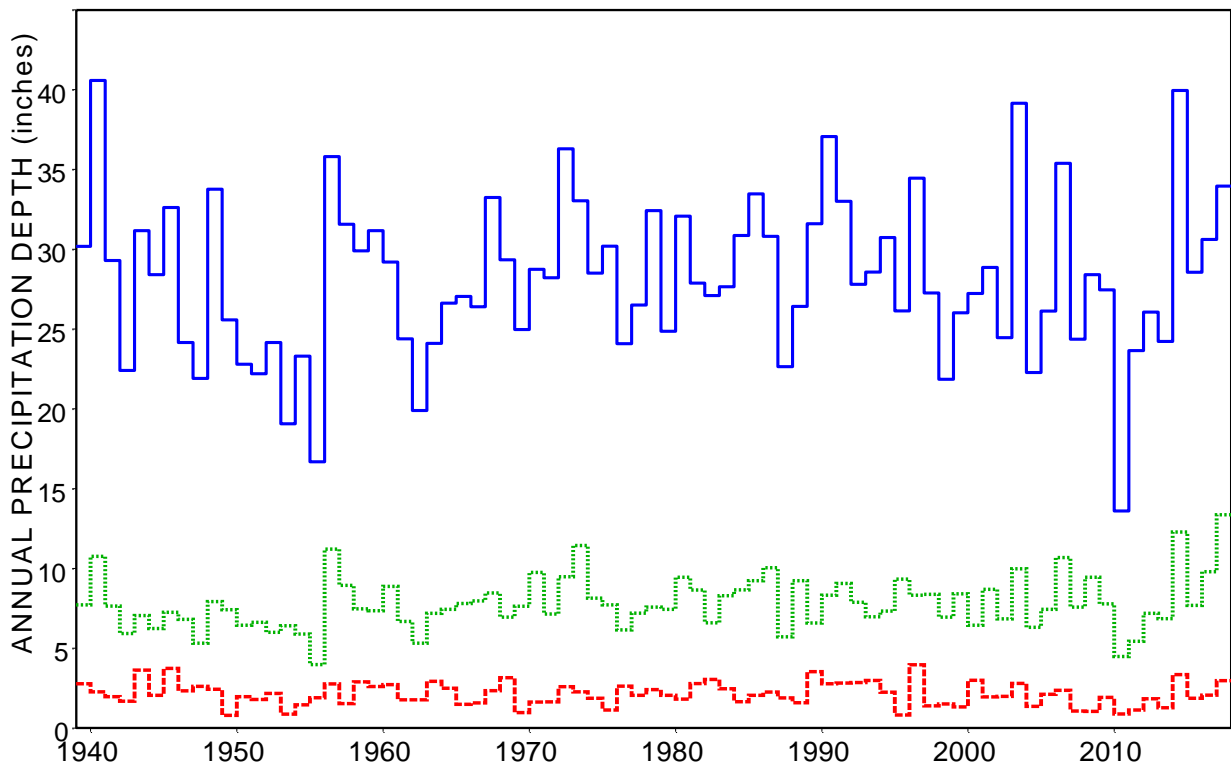


Figure 2.3 Statewide 92-Quad 1940-2018 Average of Annual Precipitation (blue solid) and Annual Two-Month Maximum (green dotted) and Minimum (red dashed) Precipitation

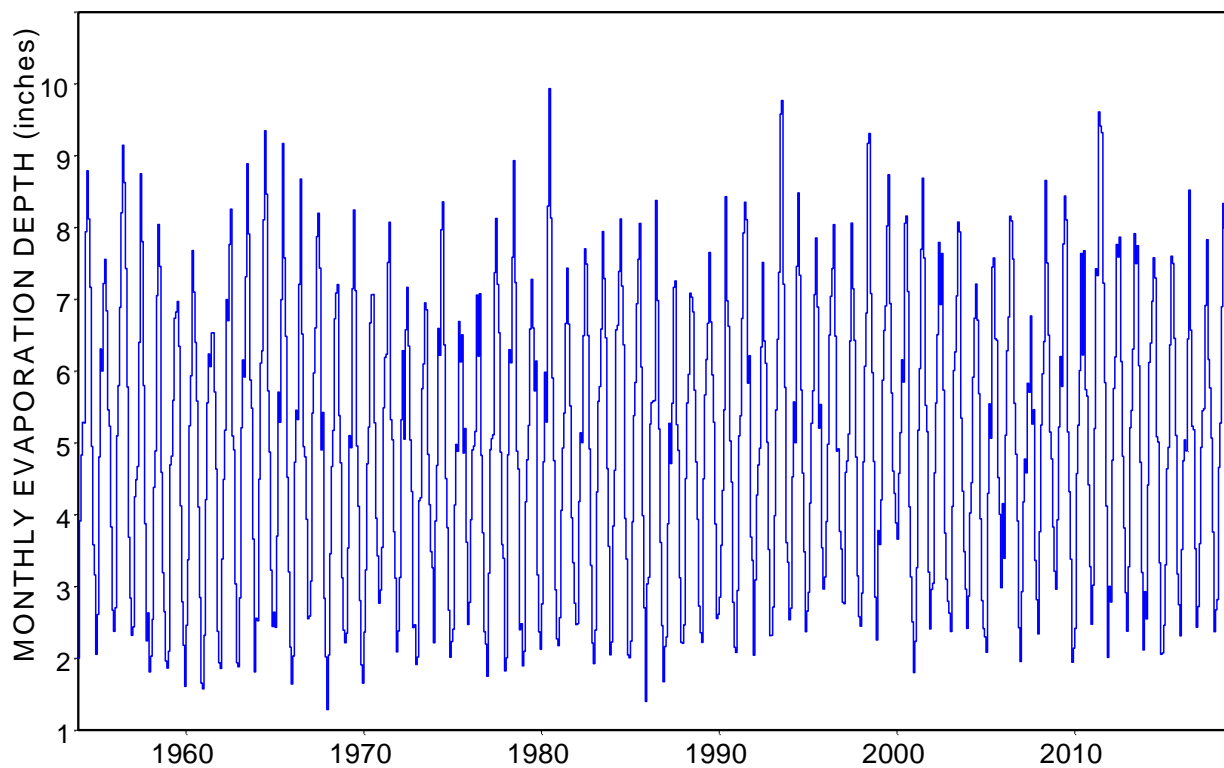


Figure 2.4 Statewide 92-Quad 1954-2018 Average of Monthly Reservoir Evaporation in inches

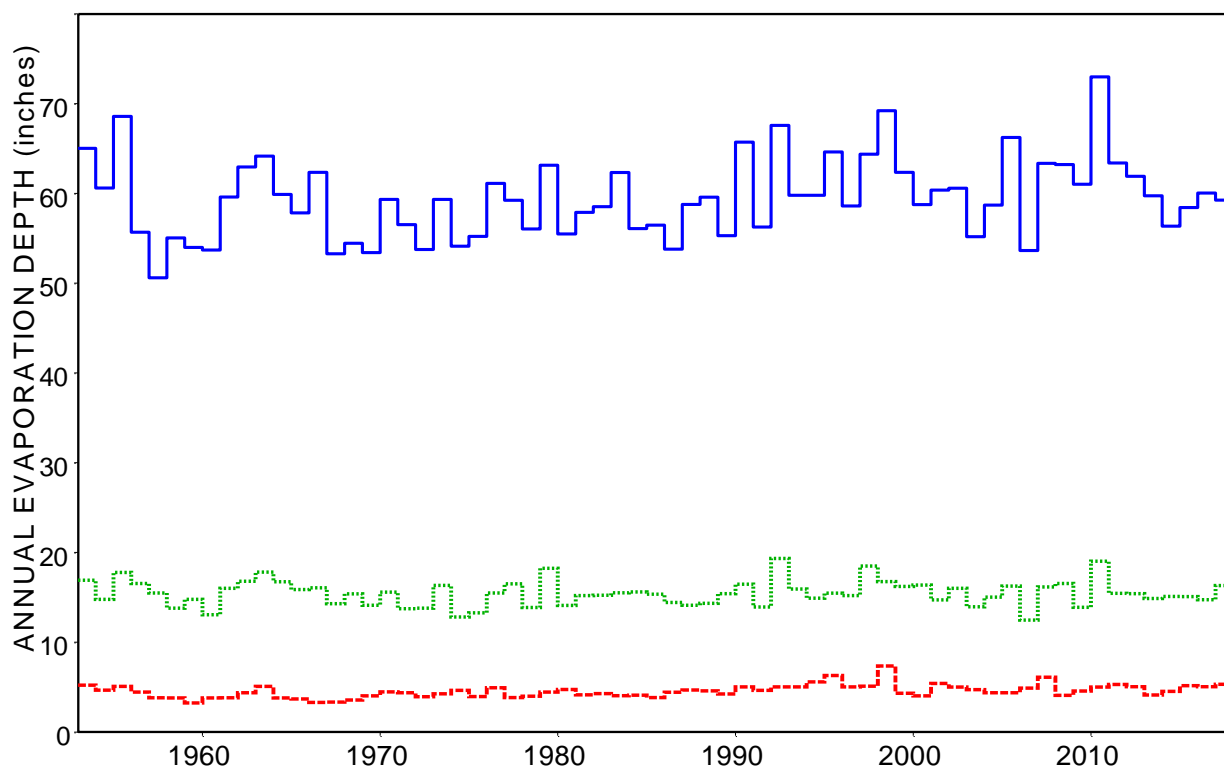


Figure 2.5 Statewide 92-Quad 1954-2018 Average of Annual Evaporation (blue solid) and Annual Two-Month Maximum (green dotted) and Minimum (red dashed) Evaporation

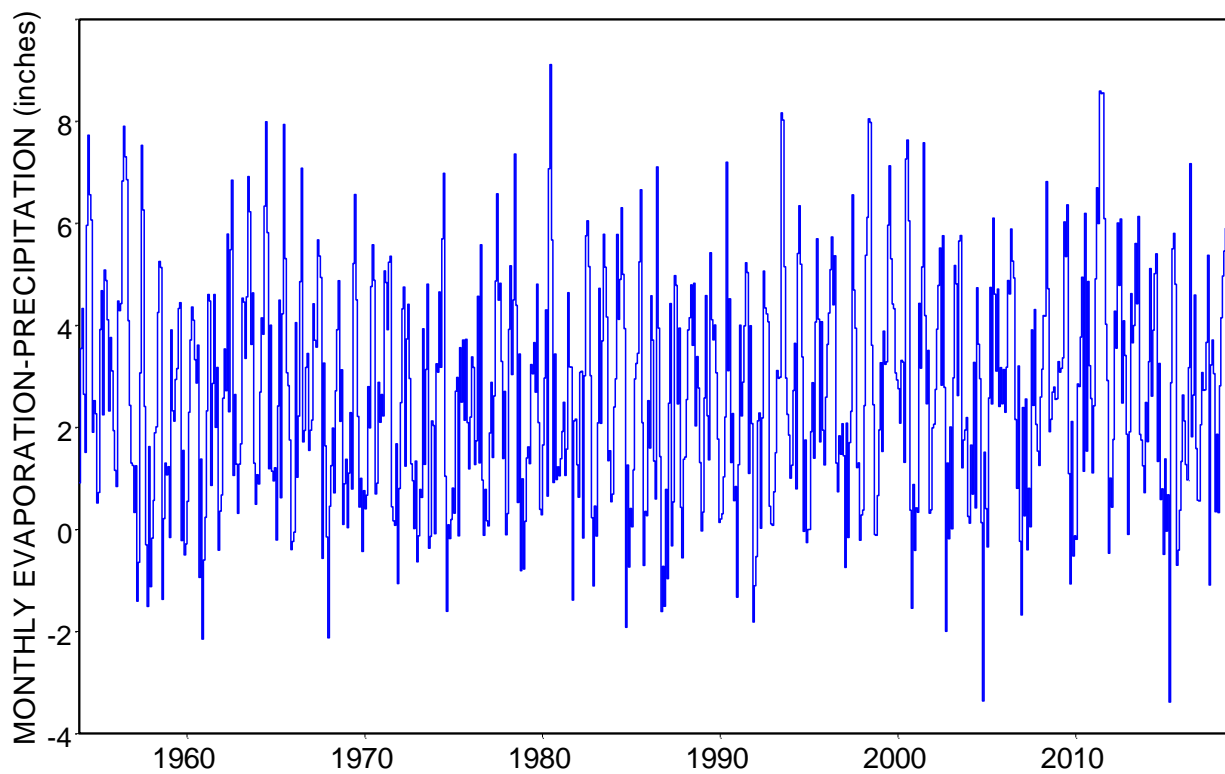


Figure 2.6 Statewide 1954-2018 Average of Monthly Net Evaporation-Precipitation in inches

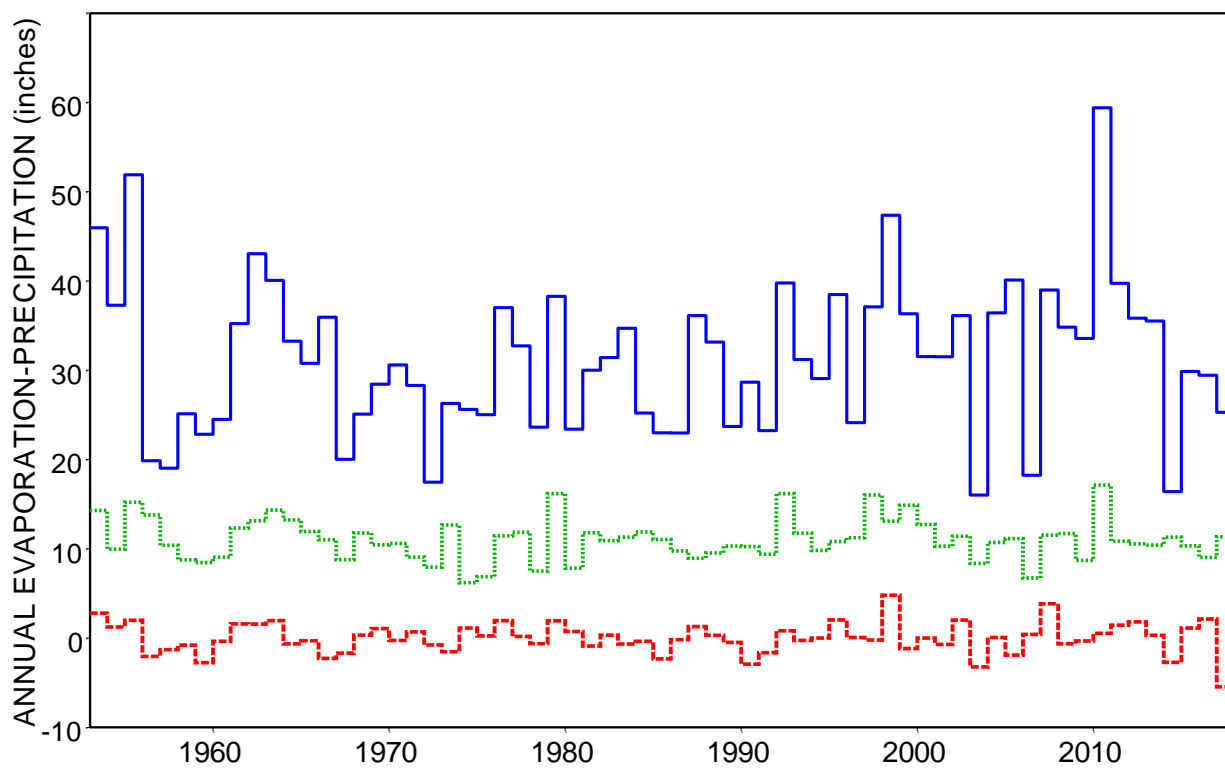


Figure 2.7 Statewide 1954-2018 Average of Annual Evaporation-Precipitation and Annual Two-Month Maximum (green dotted) and Minimum (red dashed) Evaporation-Precipitation

The time series plots show key characteristics of precipitation and reservoir evaporation. Monthly statewide precipitation and evaporation both exhibit great variability seasonally, between years, and continuously. Annual precipitation also varies greatly though the within year monthly fluctuations are removed. Annual variability is much greater for precipitation than evaporation. Seasonality is much more evident for evaporation than precipitation. Temporal variability tends to be even greater for individual quadrangles or gages. Long-term changes or trends are not pronounced in any of the time series plots of Figures 2.2 through 2.7.

### **Regression Trend Analysis of Precipitation and Evaporation Rates**

Linear regression results are presented in Tables 2.5-2.8 for the time series plotted in Figures 2.2-2.7, which consist of statewide 92-quadrangle averages of the following eight time series variables. Tables 2.5 and 2.6 also include metrics for the 92 individual quadrangles.

- January 1940 through December 2018 monthly precipitation depths, annual precipitation depths, annual minimum of two-month moving averages of monthly precipitation depths, and annual maximum of two-month moving averages of monthly precipitation depths.
- January 1954 through December 2018 monthly reservoir evaporation depths, annual evaporation depths, annual minimum of two-month moving averages of monthly evaporation depths, and annual maximum of two-month moving averages of monthly evaporation depths.

Regression computations (Eqs. 2.1, 2.2, 2.3) are activated by STAT option 2 in *HS* record field 12. The regression analysis computations are performed with variations of the last two *HS* records in Table 2.4. PE options 2 and 3 are applied in combination with SERIES options 1, 2, 4, and 5. *HYD* is executed eight times. For each execution of *HYD*, the *HIN* file contains only one *HS* record and an *ED* record. Extra variations of *HS* records can be stored after the *ED* record. The input time series of monthly precipitation and evaporation depths can be read from either the Precipitation.PPP and Evaporation.EEE files or the PrecipEvap.DSS file.

The primary reason for applying linear regression analysis to time series data is to detect and analyze long-term trends or long-term changes in the characteristics of the time series variable. The presence of long-term changes or trends is called non-homogeneity over time or non-stationarity. The annual minima and maxima of two-month averages are designed to explore trends in dry and wet hydrologic conditions or seasons, which may differ from monthly and annual means.

The results of applying linear regression to the 1940-2018 monthly precipitation depths and 1954-2018 monthly reservoir evaporation depths are shown in Tables 2.5 and 2.6, which are copied from the *HYD* output HOT file. The quantities in each column of the *HydSeries* output HOT file table created with STAT option 2 are defined earlier in this chapter on page 17.

Each line of the regression table consists of results for the time series for the quadrangle with the identifier listed in the first column. The quad identifiers are shown in Figure 2.1. The last line begins with "*TOTAL*" which is the time series identifier for the series of statewide mean depths computed as the area-weighted averages of the quantities for the 92 quadrangles.

**Table 2.5**  
**Linear Regression Analysis Results for Annual Precipitation (inches/year)**

HYD Output HOT File

Linear Regression Analysis (STAT=2) for PE Option 3

Regression Coefficients for Annual Totals (SERIES Option 2)

Site	Mean	Intercept	Slope	Intercept % Mean	Slope % Mean	Mean % Total
104	16.8514	16.9666	-0.00287969	100.6835	-0.01709	59.9069
105	17.8395	19.2040	-0.03411143	107.6485	-0.19121	63.4196
106	18.6687	19.7491	-0.02701013	105.7872	-0.14468	66.3676
107	20.9668	20.3762	0.01476480	97.1832	0.07042	74.5374
108	24.0930	23.4006	0.01731154	97.1259	0.07185	85.6511
204	16.7700	18.7799	-0.05024859	111.9854	-0.29963	59.6176
205	18.4209	18.6892	-0.00670750	101.4565	-0.03641	65.4865
206	20.3552	20.7545	-0.00998330	101.9618	-0.04905	72.3629
207	23.9810	23.6201	0.00902284	98.4950	0.03762	85.2528
208	27.8061	28.7468	-0.02351833	103.3832	-0.08458	98.8509
304	16.6634	16.0930	0.01425946	96.5771	0.08557	59.2387
305	18.2987	17.4496	0.02122764	95.3598	0.11601	65.0522
306	20.6637	20.3060	0.00894180	98.2691	0.04327	73.4596
307	22.1925	20.7444	0.03620290	93.4748	0.16313	78.8947
308	26.0006	25.0030	0.02494038	96.1631	0.09592	92.4326
309	30.8921	30.0972	0.01987262	97.4268	0.06433	109.8220
404	16.0228	16.0400	-0.00043162	100.1077	-0.00269	56.9612
405	18.1362	17.3190	0.02043111	95.4938	0.11265	64.4744
406	22.8166	24.4082	-0.03979007	106.9756	-0.17439	81.1132
407	22.9889	21.0736	0.04788172	91.6687	0.20828	81.7257
408	25.4686	24.2197	0.031222173	95.0964	0.12259	90.5413
409	29.7991	28.1259	0.04183101	94.3849	0.14038	105.9362
410	34.6429	32.2552	0.05969180	93.1078	0.17231	123.1560
411	40.9337	38.7846	0.05372598	94.7499	0.13125	145.5197
412	46.1896	47.7810	-0.03978529	103.4454	-0.08613	164.2047
413	49.0270	48.0630	0.02409839	98.0339	0.04915	174.2915
414	51.1152	50.6922	0.01057430	99.1725	0.02069	181.7152
504	15.5328	16.2852	-0.01881001	104.8439	-0.12110	55.2193
505	17.1956	17.9766	-0.01952689	104.5423	-0.11356	61.1305
506	20.6953	21.6834	-0.02470265	104.7745	-0.11936	73.5721
507	22.7435	22.2694	0.01185384	97.9152	0.05212	80.8536
508	26.3962	25.5403	0.02139835	96.7574	0.08107	93.8388
509	30.2342	28.1681	0.05165146	93.1665	0.17084	107.4829
510	33.8879	31.9219	0.04914800	94.1988	0.14503	120.4717
511	38.8006	36.8737	0.04817337	95.0338	0.12416	137.9367
512	43.6209	43.5552	0.00164237	99.8494	0.00377	155.0728
513	47.7689	46.4468	0.03305098	97.2324	0.06919	169.8189
514	50.7961	49.0987	0.04243495	96.6584	0.08354	180.5807
601	10.9358	11.3192	-0.00958357	103.5054	-0.08763	38.8770
602	14.5289	14.9546	-0.01064371	102.9304	-0.07326	51.6503
603	14.7689	15.2099	-0.01102642	102.9864	-0.07466	52.5035
604	11.6896	11.0476	0.01605042	94.5078	0.13730	41.5568
605	13.5286	13.4627	0.00164884	99.5125	0.01219	48.0944
606	18.1427	19.0724	-0.02324409	105.1247	-0.12812	64.4974
607	21.4352	20.3028	0.02831077	94.7170	0.13208	76.2024
608	24.8091	22.3204	0.06221898	89.9684	0.25079	88.1967
609	29.0848	27.2638	0.04552617	93.7388	0.15653	103.3969
610	33.1591	29.4017	0.09393588	88.6685	0.28329	117.8811
611	38.4953	36.7017	0.04484119	95.3406	0.11648	136.8514
612	44.2075	42.8780	0.03323709	96.9926	0.07518	157.1581
613	49.2792	47.4454	0.04584540	96.2787	0.09303	175.1883
614	53.3797	51.5618	0.04544945	96.5943	0.08514	189.7657
701	9.2875	9.1206	0.00417239	98.2030	0.04492	33.0171
702	15.7316	17.0348	-0.03257892	108.2837	-0.20709	55.9262
703	13.8384	13.5895	0.00622127	98.2017	0.04496	49.1955
704	14.9987	15.2529	-0.00635353	101.6944	-0.04236	53.3207
705	13.6747	13.0305	0.01610481	95.2892	0.11777	48.6137
706	19.0094	20.4836	-0.03685553	107.7552	-0.19388	67.5785
707	22.5634	21.5359	0.02568776	95.4461	0.11385	80.2132
708	25.4971	24.5465	0.02376437	96.2718	0.09320	90.6425

709	30.4999	29.5022	0.02494099	96.7290	0.08177	108.4274
710	33.2166	30.4267	0.06974613	91.6011	0.20997	118.0854
711	39.9997	39.2793	0.01801240	98.1987	0.04503	142.1996
712	46.8875	46.1677	0.01799391	98.4649	0.03838	166.6856
713	54.5601	51.2618	0.08245874	93.9547	0.15113	193.9620
714	56.7958	52.4722	0.10809165	92.3874	0.19032	201.9099
803	20.2306	40.7612	-0.51326311	201.4823	-2.53706	71.9202
804	14.6900	20.9309	-0.15602213	142.4839	-1.06210	52.2231
805	11.7920	12.0470	-0.00637479	102.1624	-0.05406	41.9208
806	16.9476	16.4323	0.01288301	96.9593	0.07602	60.2489
807	24.6357	23.6194	0.02540720	95.8747	0.10313	87.5802
808	26.8030	24.2311	0.06429952	90.4041	0.23990	95.2851
809	31.4748	29.8114	0.04158604	94.7150	0.13212	111.8934
810	34.5485	32.9150	0.04083727	95.2719	0.11820	122.8203
811	41.7646	40.3624	0.03505509	96.6426	0.08394	148.4736
812	47.5594	42.6309	0.12321188	89.6372	0.25907	169.0742
813	49.2352	41.2555	0.19949342	83.7926	0.40518	175.0317
814	57.2157	54.3990	0.07041833	95.0770	0.12308	203.4025
907	20.8689	21.3799	-0.01277640	102.4489	-0.06122	74.1891
908	22.0958	22.3544	-0.00646377	101.1701	-0.02925	78.5509
909	25.4857	24.9861	0.01248922	98.0398	0.04900	90.6020
910	35.1838	35.9091	-0.01813350	102.0616	-0.05154	125.0788
911	39.7718	39.2257	0.01365073	98.6271	0.03432	141.3892
912	44.4208	40.9453	0.08688573	92.1761	0.19560	157.9164
1008	20.4867	19.9933	0.01233561	97.5915	0.06021	72.8305
1009	24.0544	23.0456	0.02522140	95.8059	0.10485	85.5138
1010	29.4844	27.8439	0.04101213	94.4361	0.13910	104.8175
1011	34.8378	34.9847	-0.00367113	100.4215	-0.01054	123.8490
1108	17.8638	15.5703	0.05733641	87.1614	0.32096	63.5060
1109	21.8349	21.1479	0.01717597	96.8535	0.07866	77.6235
1110	25.9534	25.7371	0.00540732	99.1666	0.02083	92.2647
1210	26.2389	24.8748	0.03410249	94.8012	0.12997	93.2795
Averages	28.0952	27.5283	0.01417309	99.3348	0.01663	99.8788
TOTAL	28.1293	27.5587	0.01426439	97.9716	0.05071	100.0000

**Table 2.6**  
**Linear Regression Analysis Results for Annual Reservoir Evaporation (inches/year)**

HYD Output HOT File

Linear Regression Analysis (STAT=2) for PE Option 2

Regression Coefficients for Annual Totals (SERIES Option 2)

Site	Mean	Intercept	Slope	Intercept % Mean	Slope % Mean	Mean % Total
104	60.1806	54.8631	0.16113703	91.1641	0.26776	101.2384
105	67.2532	60.4367	0.20655999	89.8645	0.30714	113.1363
106	67.1140	61.1886	0.17955890	91.1711	0.26754	112.9021
107	64.4680	58.3267	0.18610005	90.4739	0.28867	108.4509
108	59.9298	53.4484	0.19640835	89.1849	0.32773	100.8166
204	63.4100	55.6318	0.23570333	87.7335	0.37171	106.6711
205	66.0640	57.6816	0.25401157	87.3117	0.38449	111.1357
206	66.2459	58.2898	0.24109332	87.9901	0.36394	111.4417
207	64.0388	57.2635	0.20531200	89.4200	0.32061	107.7288
208	59.2535	53.4458	0.17599213	90.1985	0.29702	99.6789
304	62.9526	57.9277	0.15226936	92.0180	0.24188	105.9016
305	63.7317	56.6321	0.21513987	88.8601	0.33757	107.2122
306	65.8443	57.1002	0.26497310	86.7200	0.40242	110.7662
307	65.9865	61.6425	0.13163596	93.4169	0.19949	111.0053
308	64.4237	62.2454	0.06600793	96.6189	0.10246	108.3763
309	59.1762	54.8169	0.13209924	92.6334	0.22323	99.5487
404	63.7689	58.5888	0.15697485	91.8767	0.24616	107.2748
405	65.6063	57.7434	0.23827125	88.0149	0.36318	110.3658
406	68.0742	57.5842	0.31787723	84.5904	0.46696	114.5173
407	69.9571	60.2120	0.29530662	86.0699	0.42213	117.6848
408	64.8203	59.2119	0.16995092	91.3478	0.26219	109.0435
409	60.9037	53.7650	0.21632262	88.2788	0.35519	102.4548
410	55.5094	48.6075	0.20914841	87.5663	0.37678	93.3803
411	53.4871	53.2888	0.00600861	99.6293	0.01123	89.9783

412	52.6778	53.0729	-0.01197115	100.7499	-0.02273	88.6169
413	43.5023	44.9495	-0.04385523	103.3268	-0.10081	73.1815
414	39.7882	36.6504	0.09508271	92.1139	0.23897	66.9333
504	68.2034	65.4052	0.08479290	95.8973	0.12432	114.7347
505	71.2029	66.8094	0.13313879	93.8295	0.18698	119.7807
506	70.1625	63.9423	0.18849045	91.1346	0.26865	118.0303
507	65.7134	59.8622	0.17730904	91.0959	0.26982	110.5459
508	63.3989	62.7445	0.01983190	98.9677	0.03128	106.6524
509	59.3906	59.3465	0.00133741	99.9257	0.00225	99.9095
510	57.6254	60.0269	-0.07277468	104.1675	-0.12629	96.9399
511	57.0069	57.9749	-0.02933331	101.6980	-0.05146	95.8995
512	54.8266	53.0635	0.05342657	96.7843	0.09745	92.2317
513	49.3191	47.4643	0.05620596	96.2392	0.11396	82.9667
514	45.6631	43.4835	0.06604828	95.2268	0.14464	76.8164
601	69.7217	72.7857	-0.09284831	104.3946	-0.13317	117.2889
602	70.4362	71.6549	-0.03693047	101.7302	-0.05243	118.4908
603	64.9498	65.7742	-0.02497916	101.2691	-0.03846	109.2614
604	68.1071	69.6656	-0.04722633	102.2883	-0.06934	114.5727
605	70.9258	69.3981	0.04629371	97.8461	0.06527	119.3145
606	68.5989	68.3227	0.00836875	99.5974	0.01220	115.4001
607	65.9775	68.0289	-0.06216313	103.1092	-0.09422	110.9903
608	65.7862	63.4892	0.06960530	96.5084	0.10581	110.6683
609	56.6631	58.1100	-0.04384481	102.5535	-0.07738	95.3211
610	56.5351	55.2130	0.04006354	97.6615	0.07086	95.1057
611	59.1220	56.3192	0.08493276	95.2593	0.14366	99.4576
612	52.8265	48.8684	0.11994015	92.5075	0.22705	88.8670
613	47.4552	42.7360	0.14300767	90.0554	0.30135	79.8312
614	48.9635	44.8163	0.12567475	91.5299	0.25667	82.3686
701	70.0294	72.2702	-0.06790277	103.1998	-0.09696	117.8065
702	62.6363	67.6028	-0.15050094	107.9292	-0.24028	105.3695
703	55.7171	59.9997	-0.12977542	107.6863	-0.23292	93.7297
704	58.1297	62.9349	-0.14561290	108.2664	-0.25050	97.7883
705	63.1371	63.8309	-0.02102407	101.0989	-0.03330	106.2119
706	62.9654	61.8376	0.03417630	98.2088	0.05428	105.9231
707	61.8725	64.0157	-0.06494620	103.4640	-0.10497	104.0845
708	57.1917	56.6310	0.01699099	99.0196	0.02971	96.2103
709	54.1528	53.0124	0.03455588	97.8942	0.06381	91.0981
710	52.3605	53.2497	-0.02694695	101.6983	-0.05146	88.0830
711	53.8055	50.3970	0.10329041	93.6650	0.19197	90.5140
712	49.9012	45.3007	0.13940963	90.7808	0.27937	83.9460
713	45.5034	41.9485	0.10772425	92.1876	0.23674	76.5478
714	46.7297	43.4511	0.09935281	92.9838	0.21261	78.6107
803	56.0411	60.9664	-0.14925228	108.7888	-0.26633	94.2747
804	55.7903	59.1102	-0.10060348	105.9507	-0.18032	93.8529
805	65.5049	60.5529	0.15006119	92.4402	0.22908	110.1952
806	68.8711	63.1453	0.17350793	91.6863	0.25193	115.8579
807	67.0091	63.1512	0.11690559	94.2427	0.17446	112.7255
808	56.7863	57.3019	-0.01562332	100.9079	-0.02751	95.5284
809	53.6083	54.0515	-0.01343162	100.8268	-0.02506	90.1822
810	52.6822	54.9090	-0.06747916	104.2269	-0.12809	88.6242
811	49.8571	47.9599	0.05748958	96.1948	0.11531	83.8717
812	47.1152	42.1804	0.14954075	89.5260	0.31739	79.2593
813	46.0614	42.5604	0.10609064	92.3993	0.23032	77.4865
814	45.7478	42.2751	0.10523602	92.4088	0.23003	76.9590
907	67.0569	60.6473	0.19422942	90.4416	0.28965	112.8060
908	59.4422	56.7211	0.08245697	95.4223	0.13872	99.9962
909	57.0765	53.9907	0.09350726	94.5937	0.16383	96.0165
910	52.8820	54.3604	-0.04479929	102.7956	-0.08472	88.9604
911	50.2551	49.9850	0.00818518	99.4625	0.01629	84.5413
912	48.4275	44.4148	0.12159797	91.7139	0.25109	81.4669
1008	65.2137	65.6507	-0.01324233	100.6701	-0.02031	109.7053
1009	63.5612	68.5465	-0.15106778	107.8432	-0.23767	106.9255
1010	59.1466	60.9042	-0.05326116	102.9716	-0.09005	99.4990
1011	54.6238	54.8186	-0.00590304	100.3566	-0.01081	91.8906
1108	64.8397	71.2460	-0.19413126	109.8803	-0.29940	109.0761
1109	61.3383	67.6720	-0.19193149	110.3259	-0.31291	103.1860
1110	61.9095	60.1288	0.05396046	97.1237	0.08716	104.1469
1210	60.8442	59.1350	0.05179330	97.1909	0.08512	102.3547
Averages	59.4845	57.3129	0.06580558	96.3923	0.10932	100.0674
TOTAL	59.4444	57.3302	0.06406738	96.4434	0.10778	100.0000

The last two lines of the *HydSeries* regression analysis table are labeled "*Averages*" and "*TOTAL*". *Averages* are simple arithmetic averages of the 92 numbers in each column. *TOTAL* is the identifier of the 93th time series representing statewide average monthly or annual precipitation or reservoir evaporation rates. The last line with the identifier *TOTAL* contains the results of applying linear regression computations to the single time series composed of statewide 92-quadrangle area-weighted average of the quantities for the 92 quadrangles.

Regression statistics for annual precipitation and evaporation for 92 quadrangles are tabulated in Tables 2.5 and 2.6. Regression statistics for statewide area-weighted averages of annual precipitation and evaporation for the 92 quadrangles are listed as the last line of Tables 2.5 and 2.6. Tables that include results for each of the 92 quad time series plus the statewide total time series, like those replicated as Tables 2.5 and 2.6, were also generated for the other six variables but are not included in this report. The last line of each of the eight tables is shown in Table 2.7. Regression statistics for statewide 92-quad averages for the six other time series variables are included in Table 2.7 along with those for annual precipitation and evaporation.

Table 2.7  
Linear Regression Analysis Results for Eight Time Series

Variable	Mean (inches)	Intercept (inches)	Slope (inches per month or year)	Intercept (% of mean)	Slope (% of 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 Precipitation	63	29
Statewide Annual Precipitation	63	29
Annual Two-Month Minimum	84	8
Annual Two-Month Maximum	51	41

The statewide mean annual precipitation and evaporation from Tables 2.5 and 2.6 are 28.1293 and 59.4444 inches/year. (Precision is obviously much less than implied by the excessive number of digits.) The means for each of the 92 quadrangles are tabulated in the second column in inches/year and in the last column as a percentage of the statewide mean.

In linear regression, an absolutely zero trend line plots as a horizontal line in a time series plot and has an intercept equal to the mean and a slope of zero. The second and third columns of Tables 2.5 or 2.6 would be the same, and the fourth column would be 0.00000000. A positive slope indicates an increase over time, and a negative slope indicates a decrease over time.

The last lines of Tables 2.5 and 2.6, which are reproduced in Table 2.7, indicate that the statewide average annual precipitation and evaporation have positive (increasing) slopes of 0.01426439 and 0.06406738 inches/year, which are 0.05071 percent and 0.10643 percent of the mean annual precipitation and evaporation of 28.1293 and 59.4355 inches/year. These statistics for eight different time series variables are tabulated in Table 2.7. The slopes for each of the 92 quads for two of the eight time series are tabulated in the third column of Tables 2.5 and 2.6. Counts of positive and negative slopes for each of the eight time series are shown in Table 2.8.

No long-term trends or permanent changes in precipitation or evaporation characteristics are evident from the time series plots and regression analyses presented here. Regression slopes vary if different sub-periods of the 1940-2018 (precipitation) or 1954-2018 (evaporation) period-of-record are adopted for the period-of-analysis. Any long-term trends, if they exist, are hidden by the great continuous monthly and annual variability in precipitation and evaporation.

### **Compilation and Analysis of Stream Flow Data**

A *SIM* or *SIMD* simulation converts naturalized stream flows to regulated and unappropriated stream flows. Naturalized flows represent the stream flow that would have occurred without the water resources development, management, allocation, and use activities modeled by the information provided in the *SIM/SIMD* input DAT file. Naturalized flows at gage sites are estimated by adjusting observed measured flows to remove the effects of water resources development, management, and use and possibly other human activities. Flow naturalization adjustments are necessarily approximate due to the complexities of river systems.

Hydrologic period-of-analysis sequences of monthly naturalized flows are stored as *IN* records in a FLO or DSS file in *SIM* input datasets and can also be included in *SIM* simulation results output files or *TABLES* output files. Simulated regulated and unappropriated stream flows recorded in *SIM/SIMD* simulation results output files and *TABLES* input and output files should conceptually exhibit the same degree of stationarity as naturalized flows.

Methods for compiling naturalized flows by adjusting observed flows are presented in Chapter 3 of this *Hydrology Manual*. The remainder of Chapter 2 focuses on analyzing the characteristics of observed and naturalized stream flows. Observed stream flows may exhibit permanent changes or long-term trends resulting from human activities. Naturalized flows should exhibit no such permanent alterations or long-term trends. The flow naturalization adjustments are designed to remove such non-stationarities. Graphical and statistical regression trend analyses provide checks on the effectiveness of stream flow naturalization adjustments.

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

Period-of-record water quantity and quality data from gaging stations throughout the United States are available from the National Water Information System (NWIS) website maintained by the U.S. Geological Survey (USGS), which includes a Texas component.

<https://waterdata.usgs.gov/nwis>

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

As of May 2019, the Texas surface water component of the NWIS includes current conditions stream flow data at 641 sites, historical observations at 889 sites, daily data at 1,039 sites, statistics for 1,016 sites, peak flow data at 1,176 sites, and field measurements at 2,375 sites. One or more daily water quantity and/or quality parameters are recorded in the NWIS by the USGS for 1,039 gaging stations in Texas. Daily flows in cubic feet per second (cfs) are available for one or more days at 907 of these gage sites. However, the periods-of-record vary greatly between sites. Several gages have complete or almost complete records of daily flows in cfs dating back to before 1900. Many sites have records of only several years or less.

Observed flows can be downloaded directly from the NWIS website in text file formats described at the website. *HEC-DSSVue* includes an import option designed to facilitate downloading of flow data from the NWIS website [2, 8]. Observed flows and other hydrologic data are downloaded to a DSS file from the USGS NWIS website using the following *HEC-DSSVue* menu option path: *Data Entry – Import – USGS Web*. This feature has been temporarily not functional recently due to modifications by the USGS of the NWIS. The *HEC-SSP Statistical Software Package* [9] includes a similar feature that has been updated by the Hydrologic Engineering Center for consistency with the recent modifications to the USGS NWIS website.

Daily flow rates in cfs can be converted to monthly rates in cfs or monthly volumes in acre-feet using the *HEC-DSSVue* option path: *Tools – Math Functions – Time Functions – Min/Max/Avg/...over period – Average over Period or Volume for Period – 1MON*. Daily or monthly flows are likewise aggregated to annual volumes. Similarly, datasets of minimum or maximum monthly or daily flow in each year can be created.

### HydSeries Features for Managing Time Series Data

*HydSeries* can be applied with monthly data for essentially any time series variable. However, as discussed earlier in this chapter, special features are included that are designed specifically for analyzing the TWDB quadrangle monthly precipitation and evaporation datasets. *HS* record field 10 PE options 1, 2, and 3 refer to data from the TWDB precipitation and evaporation datasets stored in a DSS file with filename *PrecipEvap.DSS* or text files with filenames *Precipitation.PPP* and *Evaporation.EEE* distributed with the *WRAP* software. *HS* record field 10 is blank or zero (PE=0) for any other time series variables or for precipitation and evaporation data in other input files specified by *INFILE* options 1, 2, or 3 in *HS* record field 4.

With the exception of the TWDB quadrangle precipitation and evaporation datasets accessed with PE options, all other time series variables are treated the same by *HydSeries*. The following discussion of *HydSeries* capabilities focuses on observed and naturalized stream flow but is also applicable to other time series variables.

The following time series input and output file options are selected with input parameters INFILE and OUTFILE in *HS* record fields 4 and 5 (Table 2.1).

1. *SIM* input FLO and EVA file format with records grouped by year.
2. *SIM* input FLO and EVA file format with records grouped by control point.
3. Columns of data for each time series in a text file specified by INFILE or OUTFILE.
4. DSS file with filename root.DSS in *SIM* input DSS record format.
5. DSS file with filename PrecipEvap.DSS containing TWDB quadrangle datasets.
6. Files Precipitation.PPP and Evaporation.EEE with TWDB quadrangle datasets.

INFILE options 1, 2, 3, and 4 (Table 2.1) are equivalent to *JC* record JC(1) options 1, 2, 5, and 6 described in Chapter 7. INFILE options 1, 2, and 4 are equivalent to *SIM JO* record INEV options 1, 2, and 6 described in Chapter 3 of the *Users Manual* [2]. With INFILE options 1 and 2, *HydSeries* time series input records have the same organization and format as *IN* and *EV* records in a *SIM* input FLO file or EVA with the exception noted in the next paragraph. Likewise, the *HydSeries* DSS input file with filename root.DSS is identical to the *SIM* hydrology DSS input file, with the exception of the feature described in the following paragraph.

The record identifiers for the records in the *HydSeries* input and output files are specified by input parameters INID and OUTID in *HS* record fields 8 and 9. These two-character record identifiers are the first two characters of text file records and pathname part C of DSS records. "IN" may be entered in *HS* field 8 or 9 for INID or OUTID, resulting in records that are the same as *SIM* FLO file input records or DSS records that are the same. However, INID or OUTID may be any two-character identifier or may be blank meaning no identifier is included in the time series records. The identifiers are simply labels that have no effect on *HydSeries* operations.

With INFILE and OUTFILE options 1, 2, and 3, the time series input data is stored in the specified file in different alternative formats. With options 1 and 2, records can be copied from a *SIM* input FLO or EVA file and inserted in a INFILE-specified file, without modification. With INFILE options 1 and 2, the time series input data are in standard *SIM* input record format grouped by either year (*HYD* INFILE or *SIM* INEV option 1) or by control point (INFILE or INEV option 2). All time series records in the *HydSeries* input file are read. The time series input records include control point identifiers. Site identifier *SI* records are not required. However, if *SI* records are included in the HIN file, only the time series with the *SI* record identifiers are included in the final dataset adopted for the analyses and output files.

INFILE and OUTFILE option 3 allows the times series to be stored as columns of data. The HIN input file in Table 2.9 with INFILE option 4 creates an OUTFILE option 3 output file for which the first 18 records (lines) are also reproduced in Table 2.9. This columnar output file can also be read as an INFILE option 3 input file, with filename extension TSF (default), FLO, or EVA. The first 15 months of naturalized flows at four control points from the example from the *WRAP Fundamentals Manual* [3] are shown in Table 2.9. Though the data were actually read from a DSS file in the Table 2.9 example, these data columns could be also be created with the *WRAP* program *TABLES* with TIN file specification provided by a 2NAT record [2]. The INFILE option 3 column format is also useful when working with Microsoft Excel. The columns of data in the HIN output TSF file of Table 2.9 can be converted back to a DSS file or *SIM* input FLO file using *HydSeries* INFILE option 3 and OUTFILE options 1, 2, or 4.

Table 2.9  
Conversion from DSS to Columnar Format

```

**          1          2          3          4          5
**345678901234567890123456789012345678901234567890

```

HYD Input HIN File

```

HS  1940      2017    4    3          IN
SI      4      HEMP    Whit    High    Camer
ED

```

HYD Output TSF File

```

TS      4      Hemp      Whit      High      Camer
1940    1      31649.0    11746.0    14754.0    4226.0
1940    2      149252.0    6676.0    14791.0    21590.0
1940    3      27695.0    4427.0    8624.0    5258.0
1940    4      196282.0    41228.0    125139.0    106875.0
1940    5      365200.0    131761.0    149370.0    118827.0
1940    6      666231.0    354218.0    484655.0    246700.0
1940    7      1169486.0    100957.0    266624.0    402103.0
1940    8      270115.0    267803.0    254009.0    19420.0
1940    9      104997.0    68217.0    75863.0    8136.0
1940   10      50295.0    9062.0    16362.0    4495.0
1940   11      1583495.0    266476.0    581172.0    506043.0
1940   12      2555544.0    197232.0    579843.0    610025.0
1941    1      979247.0    58622.0    242060.0    315015.0
1941    2      1259427.0    282131.0    610386.0    455249.0
1941    3      1410847.0    165165.0    436244.0    479749.0

```

Any number of comment **\*\*** records, not read by the computer, can be inserted any place in *HydSeries* input files. For a **INFILE** option 3 input file, the first line of actual computer-read information contains identifiers for each time series. The remaining lines of data consist of the time series quantities in chronological order, followed by an *ED* record that ends the dataset. Records (lines of data) after the *ED* record are not read by the computer.

The list of time series identifiers in an **INFILE** or **OUTFILE** option 3 tabulation begins with the term **TS** followed by the number of identifiers (**NID**) and the **NID** identifiers **TSID(I)**. The "TS" and variables **NID**, and (**TSID(I),I=1,NID**) are read or written in the following format.

A2, I6, NID×(4x,A6)

The quantities for the **NID** time series are tabulated in fields of 10-character width, with any number of digits up to nine to the right of the decimal in an input file. The **INFILE** option 3 routine skips over without does actually reading the first eight (8) characters in each line of the time series data (8x,NID×F10.0). However, **OUTFILE** option 3 tabulates the year and month as the first eight characters, as in Table 2.9, in the following format: I5,I3, NID×F10.1

**INFILE** option 4 reads time series data from a DSS file with filename root.DSS. *SI* records are required. Only records with identifiers listed on *SI* records in the HIN file are read from the DSS file. Only data for the period of years defined by **YRBEG** and **YREND** in *HS* record fields 2 and 3 (Table 2.1) are read.

Input parameter SERIES in *HS* record field 13 controls further adjustment of the data sequences. The final adopted data series consists of one of the following.

- original monthly quantities
- aggregated annual quantities as either totals or means of monthly quantities
- minimum or maximum monthly quantity in each year
- annual minima or maxima of the MA-month forward moving averages

The number of months MA used in computing moving averages is specified in *HS* record field 14. The averaging period MA includes the current month and M-1 future months. The quantities may be further modified by multiplying by MX entered in *HS* record field 15.

Computation of basic statistics and performing linear regression analysis are controlled by STAT in *HS* record field 12. Statistical analysis results are recorded in the HOT file. STAT options 1 and 3 created tables of basic statistics. STAT option 2 consists of linear regression analysis of each time series. Option 4 creates organized tabulations of the complete monthly or annual time series.

*HS* record field 5 input parameter OUTFILE specifies the type and organization of the file in which *HydSeries* writes time series data. Time series data read by *HYD* from any input file in any format can be recorded by *HYD* in a different file in the same or different format. One application of *HydSeries* is to thus convert text files to DSS or vice versa.

### **Stream Flow Characteristics**

Characteristics of river flows throughout Texas are investigated in a 2014 report entitled *River System Hydrology in Texas* [10]. Stationarity (homogeneity over time), or lack thereof, and variability represent two different flow characteristics. Flows in all of the rivers of Texas, as well as many other rivers throughout the world, exhibit extreme variability. Flows fluctuate greatly and continuously. Stationarity or homogeneity refers to lack of long-term changes or trends. Permanent changes or long-term trends vary greatly between sites on the streams of Texas and are difficult to detect and measure due to the great continuous variability. Long-term changes or trends vary greatly with location but are generally small compared to the continuous extreme flow variability that characterize river flows throughout Texas.

Four key observations regarding the characteristics of the flows of the rivers of Texas are as follows [10].

- Variability is dramatic with extremes of severe multiple-year droughts and major flood events as well as seasonality and continuous fluctuations.
- Long-term changes in observed monthly and annual mean flows at most gage sites appear to be relatively small but may be great just downstream of major dams.
- Water resources development, management, and use tends to affect low flows and high flows more than average or median flows.
- Flow variability and long-term changes vary depending on whether daily, monthly, or annual time intervals are adopted for aggregating and expressing quantities.

Construction and operation of dams and other facilities, water supply diversions, return flows from surface and groundwater supply sources, and other aspects of population and economic growth affect stream flow [10]. The effects are very different at different sites. For example, the flow of the San Antonio River below the City of San Antonio has increased over the last 100 years as a result of wastewater treatment plant discharges accompanying increased water use supplied from the Edwards Aquifer and increased impervious land cover due to urbanization. The flow of the Rio Grande has decreased greatly due to construction of Amistad, Falcon, and other reservoirs and development of irrigated agriculture. The Trinity River is representative of many rivers that have experienced a decrease in flood flows due to construction of flood control reservoirs and increase in low flows due to return flows (wastewater treatment plant effluent) associated with increases in municipal and industrial water use. Stream flow immediately below a dam is greatly affected by reservoir operations but the effects diminish with distance downstream.

Stream flow rates change continuously. The USGS gage measurements are recorded as mean daily flows in cubic feet per second (cfs). Daily means are averaged over the days of each month to obtain monthly means. Variability is reduced with the larger averaging time interval. Maximum flood peaks are lowered and minimum flows during low flow periods increase with an increase in the size of the measurement or computational time interval.

The 1950-1957 drought is the most hydrological severe drought to occur over much of Texas over the past more than 100 years. The 2010-2014 and other severe droughts are also evident in historical observed precipitation and stream flow. River flows in most of Texas were very high during much of 2015 and 2016, below average in 2017, and significantly above average during 2018. The first half of 2019 has been very wet for most of the state.

### Units of Measure for Flow Rates

Actual stream flow rates vary continuously. Simulation studies employ a monthly or daily computational time step. Mean flow rates in units of cubic feet per second (cfs) may be adopted to express daily, monthly, and annual flow quantities. Mean daily, monthly, and annual flow volumes (rates) in acre-feet per computational time interval are commonly adopted for WRAP/WAM studies. Relevant conversion factors are as follows.

$$\begin{aligned}
 1.0 \text{ acre-foot per day} &= 0.50416667 \text{ cubic feet per second (cfs)} \\
 1.0 \text{ cfs} &= 1.983471 \text{ acre-feet/day} \\
 1.0 \text{ cfs} &= 723.967 \text{ acre-feet per 365-day year} \\
 1.0 \text{ cfs} &= 725.950 \text{ acre-feet per 366-day leap year} \\
 1.0 \text{ day} &= 86,400 \text{ seconds} \\
 1.0 \text{ acre-foot} &= 43,560 \text{ cubic feet} \\
 1.0 \text{ second-foot-day (sfd)} &= (1.0 \text{ ft}^3/\text{s}) \times (1.0 \text{ day}) = 86,400 \text{ ft}^3
 \end{aligned}$$

Monthly and daily flow rates in WRAP/WAM simulation computations and input data are expressed in units of acre-feet/day or acre-feet/month. The USGS records observed daily flow rates as daily means in cfs and expresses volumes in second-foot-day (sfd). All days have the same length of 86,400 seconds. The 12 months of the year have lengths of either 28, 29, 30, or 31 days. February has 29 days in leap years and 28 days in all other years.

## **Graphical Analysis of Observed and Naturalized Stream Flows**

Stream flow at U.S. Geological Survey (USGS) gaging station 08096500 on the Brazos River near Waco in Central Texas is adopted as an illustrative example of both flow characteristics and analysis methods. This gage site is control point BRWA41 which is one of 77 primary control points with naturalized flows included in WRAP input dataset for the Brazos River Basin water availability model (WAM). The original Brazos WAM 1940-1997 hydrologic period-of- analysis was recently extended though 2017 using approximate methods [12]. The gage site has a watershed area of about 20,000 square miles. Seven large reservoirs with conservation storage capacities ranging from 115,900 to 1,363,400 acre-feet and many smaller reservoirs are located upstream of this gage site. Three of the seven large reservoirs (Whitney, Aquilla, and Waco) are multiple-purpose projects operated by the Corps of Engineers that include additional flood control pool capacities of 1,363,400, 93,600, and 519,800 acre-feet [12].

Daily flows in cfs at this gage are downloaded from the USGS National Water Information System (NWIS) website to a DSS file. The daily flows are aggregated to monthly and annual flows within *HEC-DSSVue*. Naturalized monthly flows from the Brazos WAM [12] are also copied to the DSS file and aggregate to annual volumes within *HEC-DSSVue*. These time series and other time series derived therefrom are plotted with *HEC-DSSVue*. The plots of Figures 2.8 through 2.16 are employed to analyze the river flow at this location. These plots illustrate the tremendous variability characteristic of river flows throughout Texas. Impacts of water resources development and management are also evident in the plots.

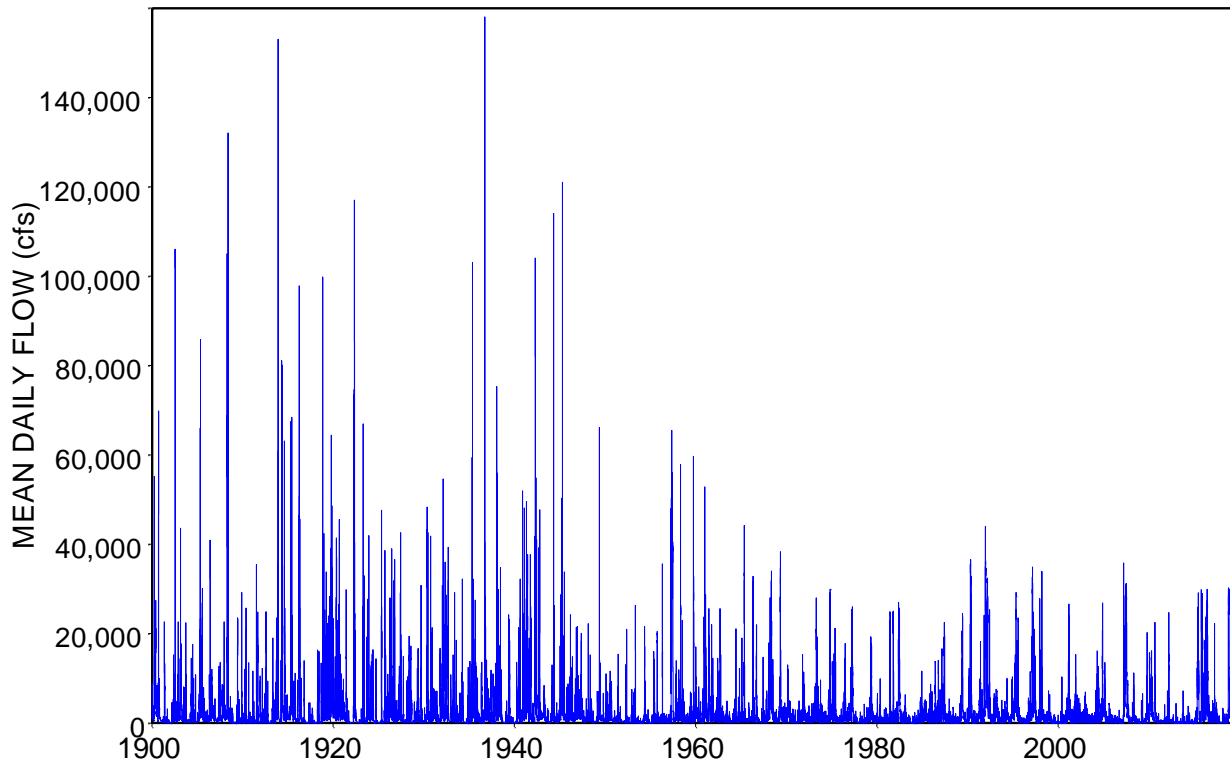


Figure 2.8 Mean Daily Flows in cfs at the USGS gage on the Brazos River at Waco during October 1, 1898 through January 20, 2019

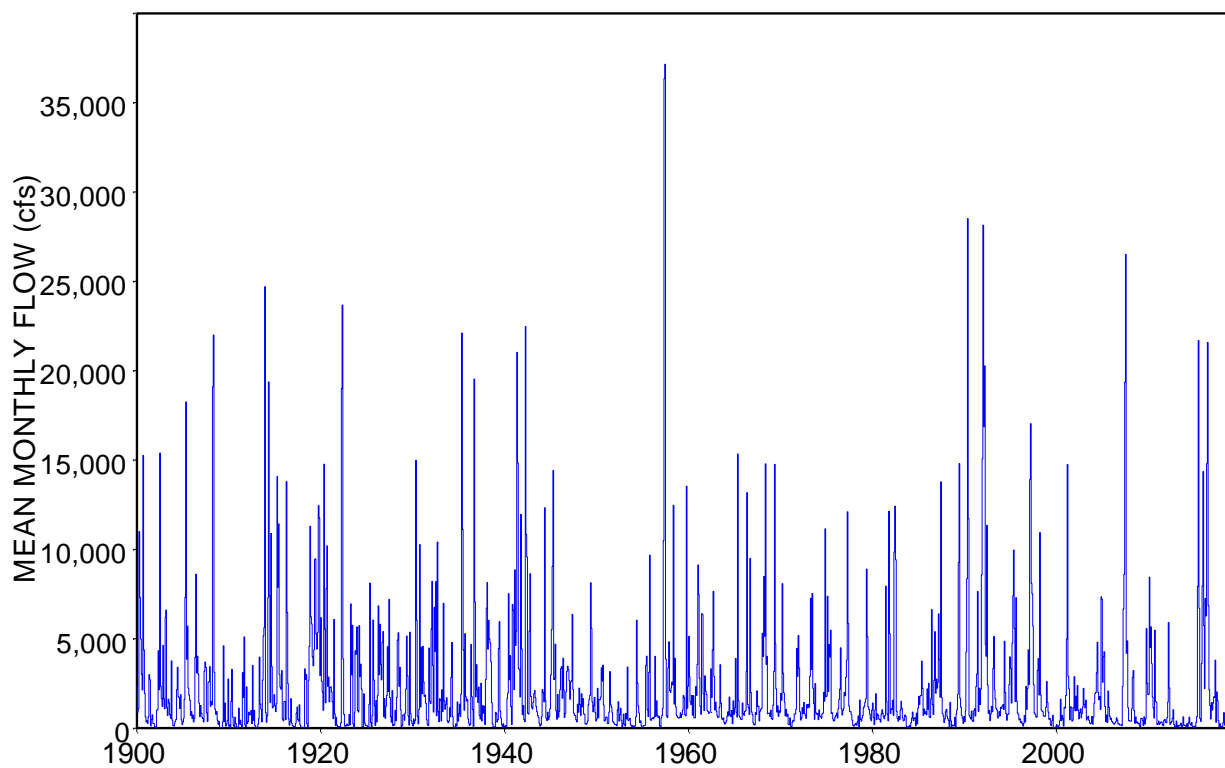


Figure 2.9 Mean Monthly Flows in cfs at the USGS Gage on the Brazos River at Waco during October 1898 through December 2018

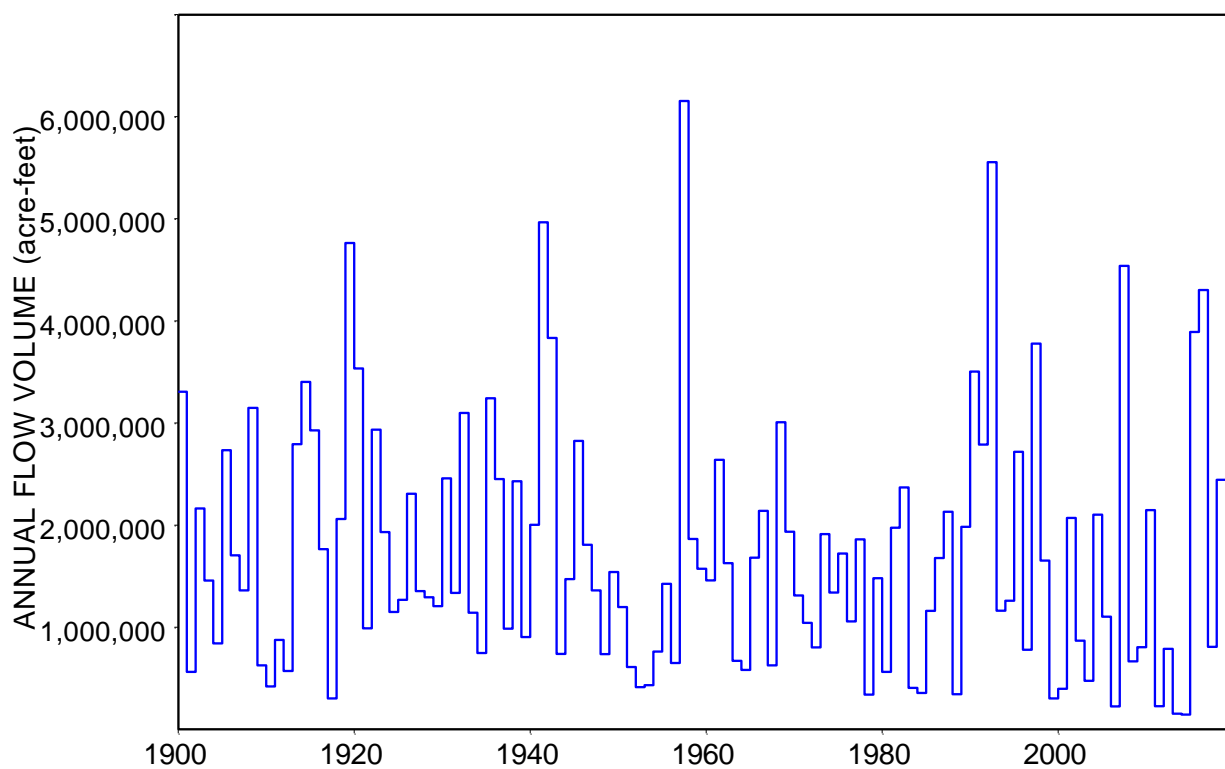


Figure 2.10 1899-2018 Annual Flows in acre-feet at the Gage on the Brazos River at Waco

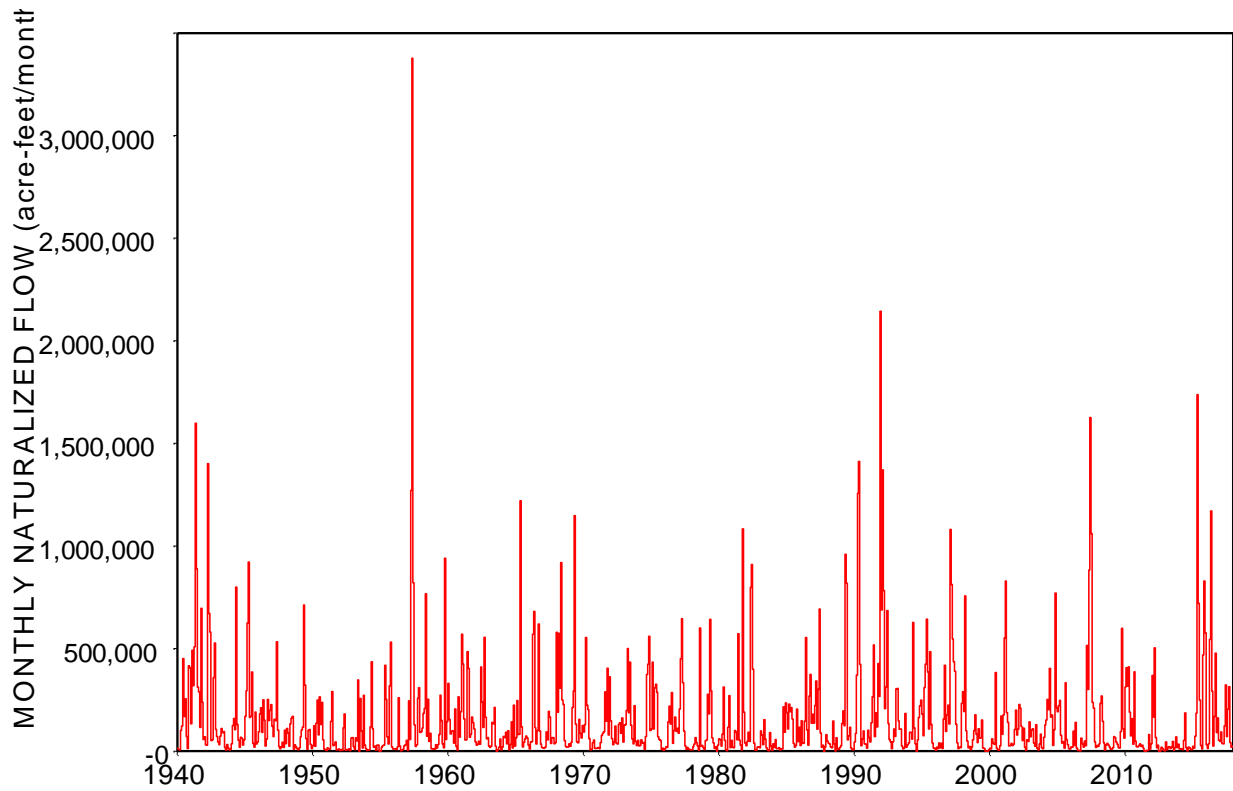


Figure 2.11 Monthly Naturalized Flows of the Brazos River at Waco in acre-feet [12]

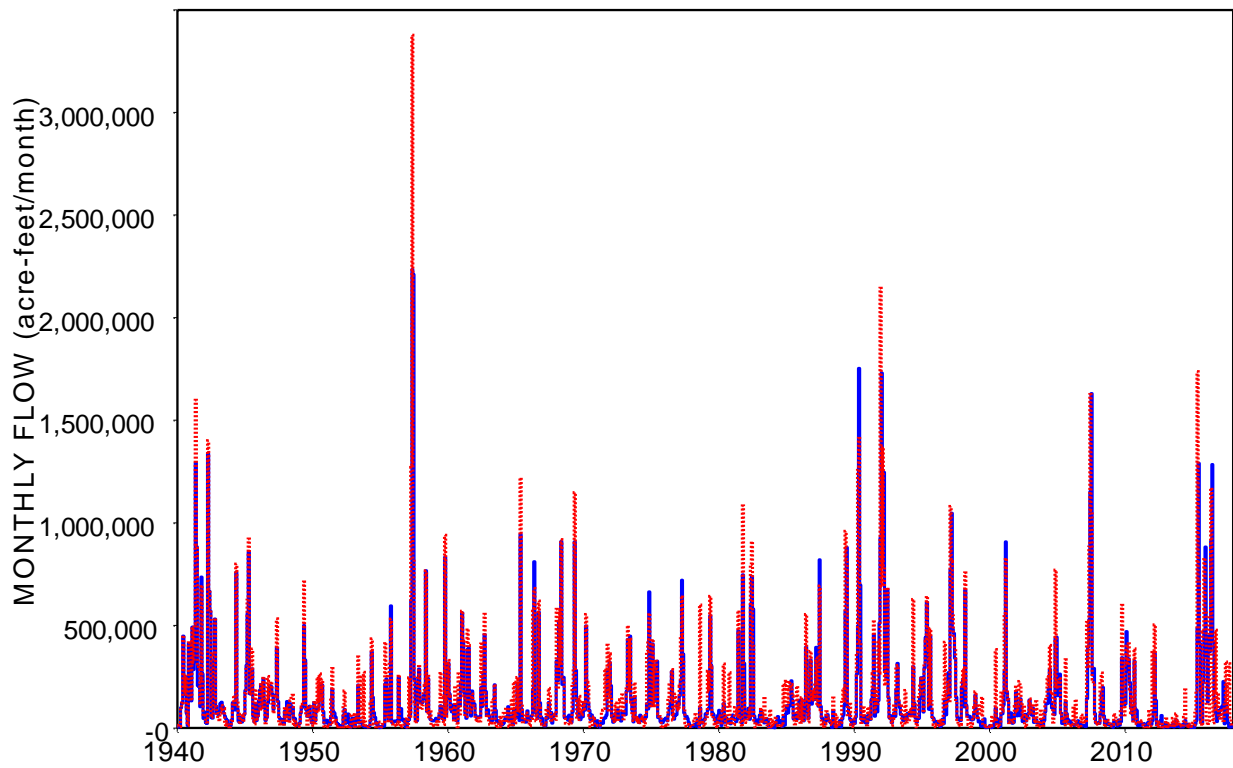


Figure 2.12 Monthly Observed (blue solid line) and Naturalized (red dotted line) Flows of the Brazos River at Waco in acre-feet

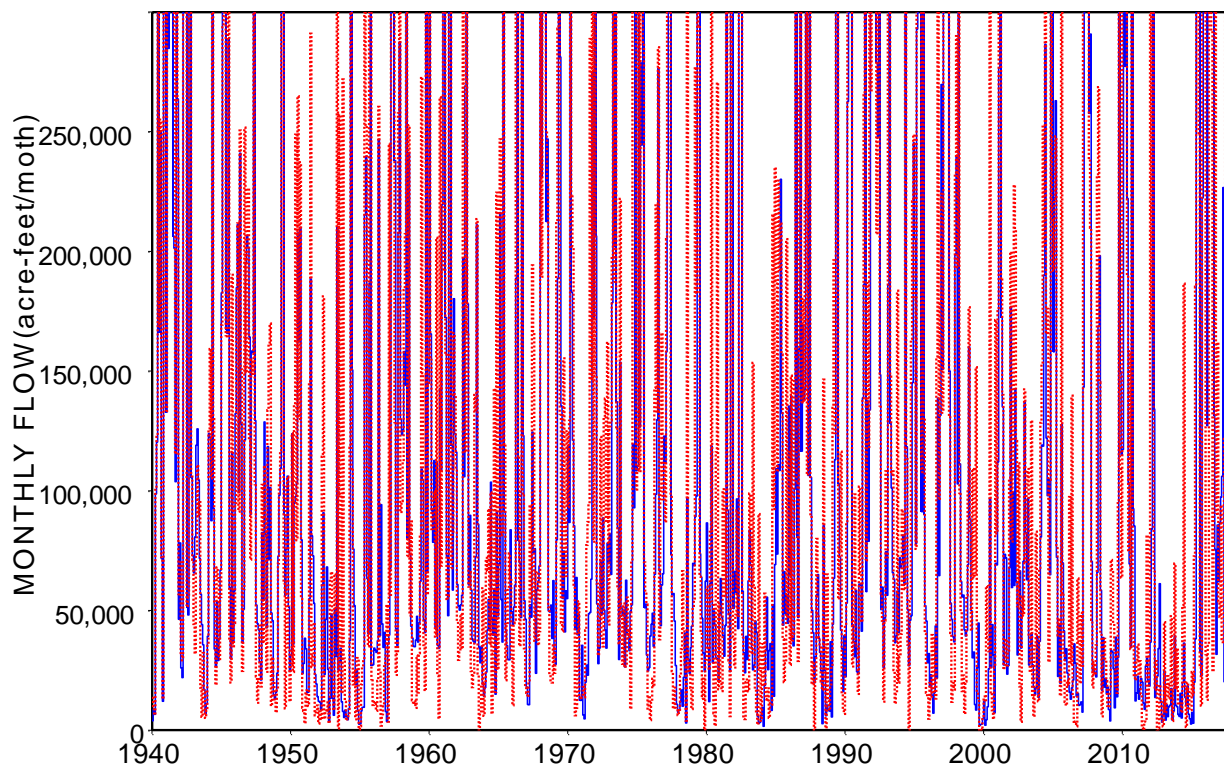


Figure 2.13 Monthly Observed (blue solid line) and Naturalized (red dotted line) Flows of 300,000 acre-feet/month or Less of the Brazos River at Waco

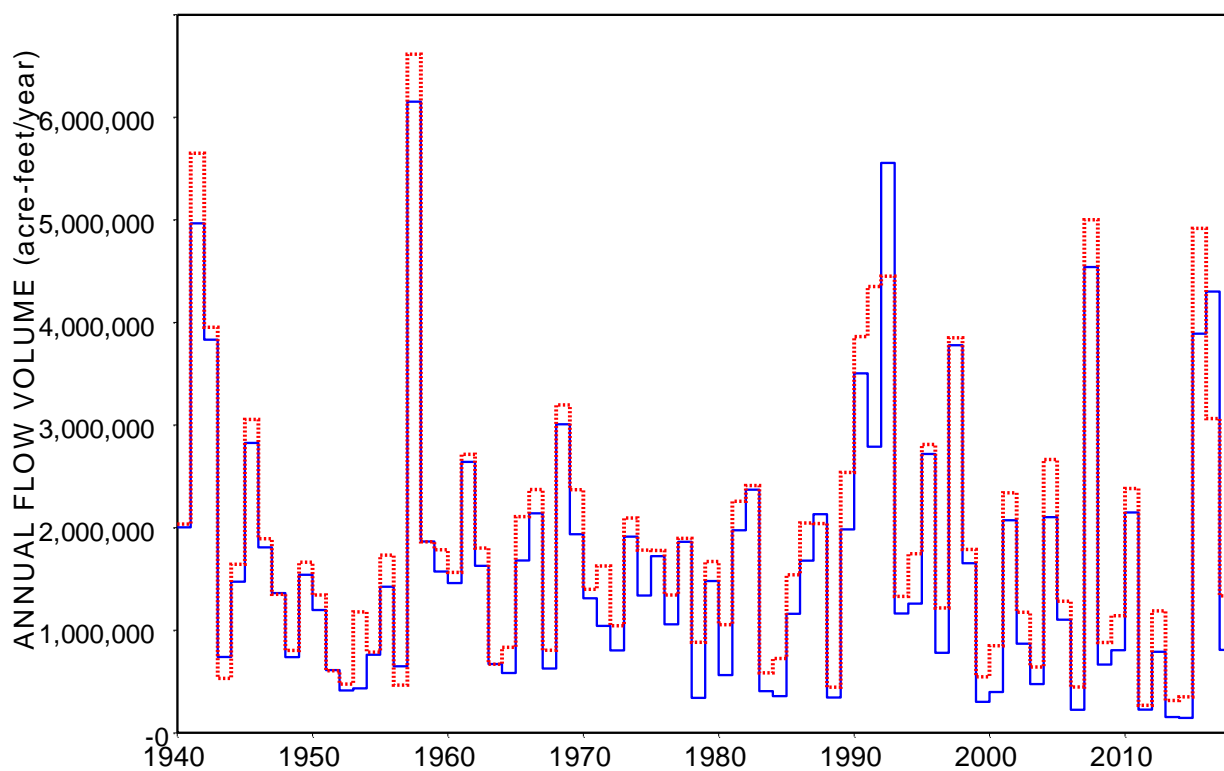


Figure 2.14 Annual Observed (blue solid) and Naturalized (red dotted) Flow

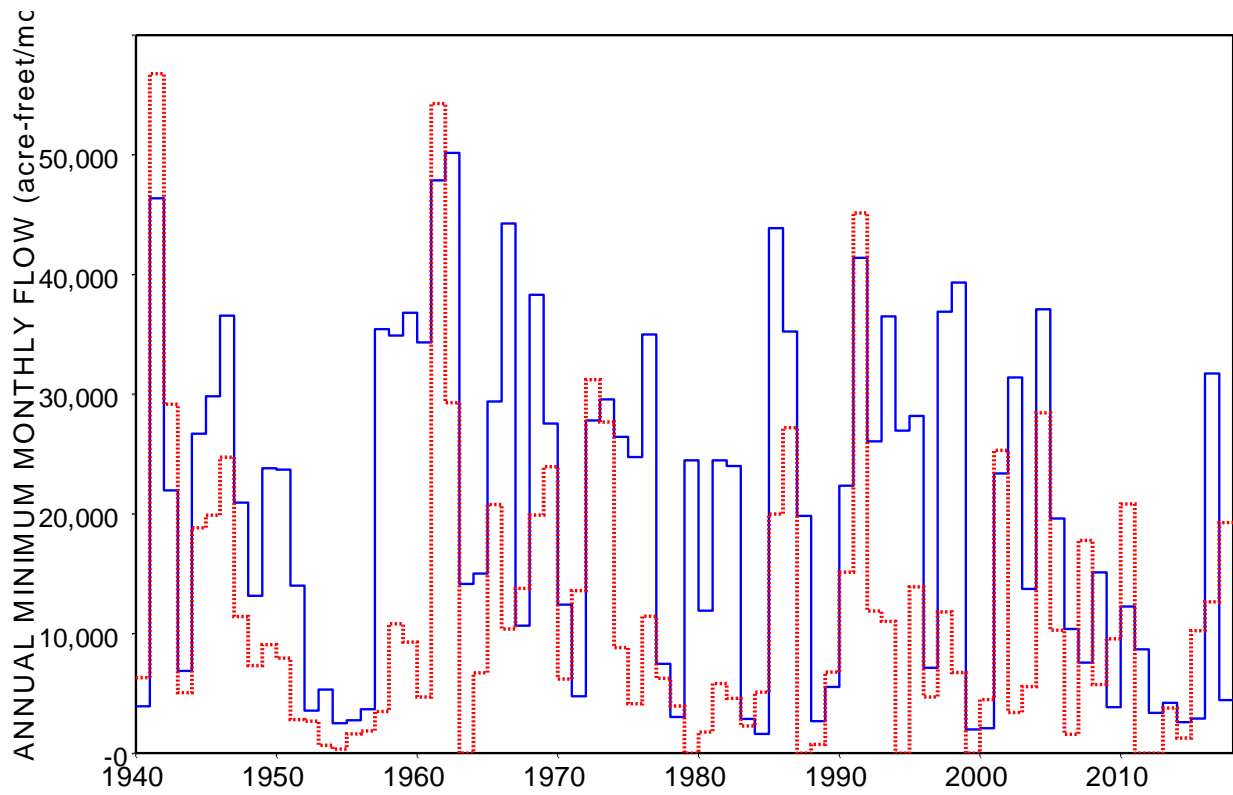


Figure 2.15 Observed (blue solid line) and Naturalized (red dotted line)  
Minimum Monthly Flow Each Year in the Brazos River at Waco

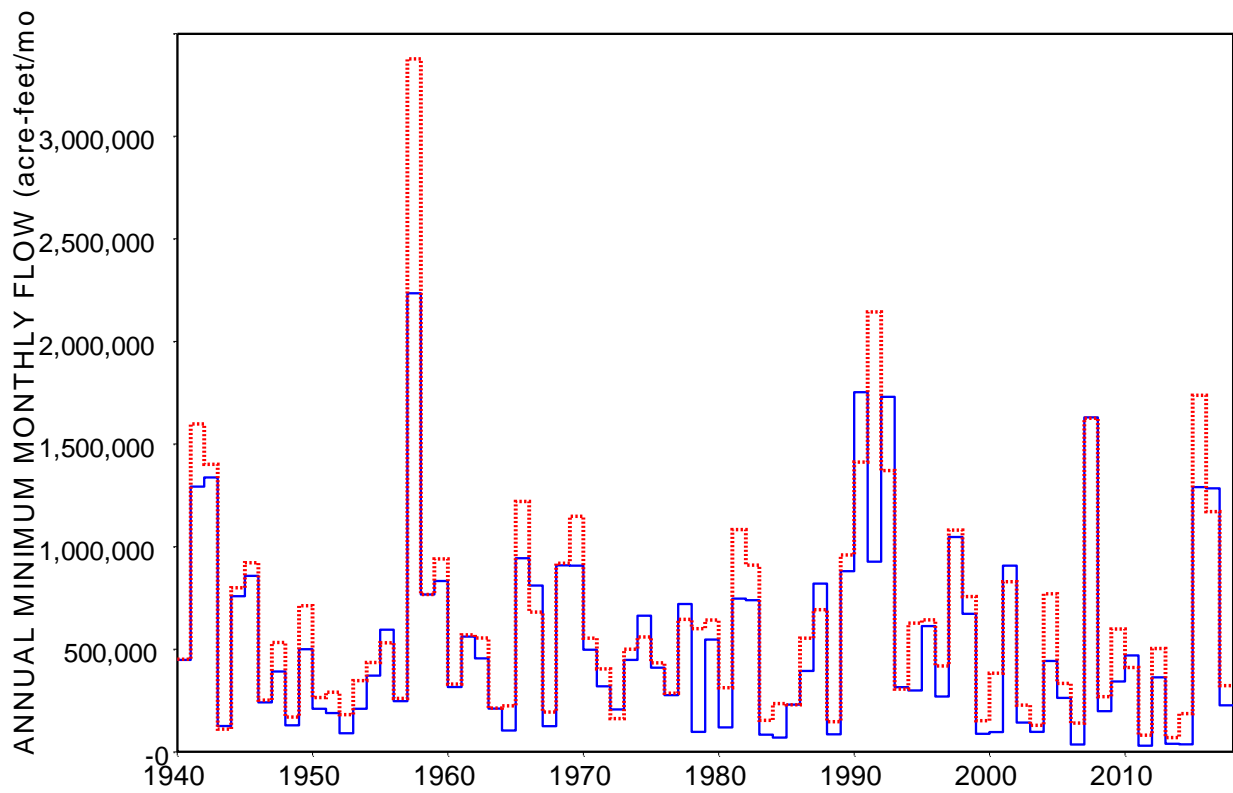


Figure 2.16 Observed and Naturalized Maximum Monthly Flow Each Year

The effects on flood flows of Possum Kingdom, Whitney, and Waco Reservoirs, with initial impoundment in 1941, 1951, and 1965, located upstream of the Waco gage on the Brazos River are evident from the plot of Figure 2.8 of daily gaged flows. Aquilla Reservoir with initial impoundment in 1983 also reduces flood flows at this site. The Fort Worth District of the U.S. Army Corps of Engineers operates the flood control pools of Whitney, Waco, and Aquilla Reservoirs based on a maximum allowable flow rate of 25,000 cfs at the Waco gage along with other downstream operating gages with different allowable flow rates and other tributary dams.

The pronounced decrease in daily flood flows due to flood control reservoir operations shown in Figure 2.8 is dissipated in the monthly means of Figure 2.9 and annual flow volumes of Figure 2.10. The storage attenuation impacts on river flows at sites downstream of flood control reservoirs are dissipated with an increase in time interval used to record observed mean flow rates or flow volumes and to perform simulation computations. The effects of dams on river flows also diminish with distance downstream from the dam.

Low flows are especially important in water availability modeling. Day-to-day and month-to-month variability during periods of low flow tends to be obscured in daily and monthly time series plots by the scale required to include flood peaks in the plots. *HEC-DSSVue* includes features for zooming in on selected ranges of flows. Higher flows are excluded in Figure 2.13 to focus on a selected range of lower flows. Annual series of the minimum monthly flow in each year or minima of moving averages for specified durations can also be plotted as illustrated by Figure 2.15.

Observed and naturalized flows from January 1940 through December 2017 are compared in Figures 2.12, 2.13, 2.14, 2.15, and 2.16. Observed gaged flows are plotted as a solid blue line in each of these figures. Naturalized flows are plotted as a dotted red line.

The annual flow volumes plotted in Figure 2.14 are generally higher for naturalized flow than for observed flow. The flow naturalization adjustments tended to increase annual flow volumes. The minimum monthly flow in each of the 78 years of 1940-2017 are plotted in Figure 2.15. The naturalized flows are much lower than observed flows in most years in Figure 2.15. Conversely, in Figure 2.16, the maximum monthly naturalized flows are higher than the observed maximum monthly flows in most of the 78 years of 1940-2017.

Permanent changes or long-term trends in the characteristics of 1899-2018 monthly and annual observed flows are not clearly evident in Figures 2.9 and 2.10. The major decrease in daily flood flows due to flood control reservoir operations shown in Figure 2.8 is dissipated in the monthly and annual quantities of Figures 2.9 and 2.10 as previously noted. Although no permanent long-term trends in the median or mean of flows are visually pronounced in the plots, low flows appear to perhaps gotten lower and more frequent since the 1960's.

Monthly naturalized flows at this site from the Brazos WAM [12] in acre-feet/month for a 1940-2017 hydrologic period-of-analysis are plotted in Figure 2.11. If the flow naturalization process was successful, the naturalized flows should exhibit no long-term fluctuations or trends. This appears to be the case based on a visual inspection of the plots. The naturalized monthly flows are extremely variable but appear to be stationary. Stationarity or lack thereof is further analyzed in the next section of this chapter employing linear regression trend analysis.

## Statistical Analysis of Observed and Naturalized Stream Flows

Basic statistics are computed and linear regression analyses are performed with *HydSeries* for the January 1940 through December 2017 monthly observed and monthly naturalized flows at the USGS gage site on the Brazos River near Waco plotted in Figures 2.11 and 2.12 and the annual series derived therefrom plotted in Figures 2.14, 2.15, and 2.16.

### HydSeries Data Files

The previously cited May 2019 Brazos WAM Report [12] is accompanied by WRAP input files that include a hydrology DSS file with 1940-2017 monthly naturalized flows at 77 control points and auxiliary DSS files with observed flows and other hydrologic time series datasets. The control point identifiers for all 77 primary control points can be included on *SI* records in a HIN file to read the entire Brazos WAM dataset of 1940-2017 naturalized flows for analysis. Likewise, any number of other time series can be added to the *HydSeries* DSS input file with their identifiers added to the *SI* records in the HIN file.

For brevity, the input file adopted in the example presented here is limited to a dataset with only two monthly time series excerpted from the datasets noted above [12]. The observed (USGS) and naturalized (NAT) monthly time series are read by *HydSeries* from a DSS file with the filename Waco.DSS. The pathnames for the two DSS records are replicated in Table 2.10.

Table 2.10  
DSS Record Pathnames for the Input File with Filename Waco.DSS

Part A	Part B	Part C	Part D	Part E
WACO	NAT	IN	31Jan1940-31Dec2017	1MON
WACO	USGS	IN	31Jan1900-30Nov2018	1MON

Alternative time series file formats may be employed, and *HydSeries* may be used to convert between formats. For example, the HIN file in Table 2.11 converts the file Waco.DSS (INFILE option 4) to a text file in *SIM* input FLO file format (OUTFILE option 1). The HIN file in Table 2.12 converts the FLO file back to the original DSS file with Table 2.10 DSS records.

Table 2.11  
*HYD* Input HIN File for Converting DSS File to FLO File

```

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

Table 2.12  
*HYD* Input HIN File for Converting FLO File to DSS File

```

HS  1940      2017    1    4  FLO      IN  IN
ED
```

With the time series data read from a DSS input file (INFILE option 4), time series identifiers (control points or other arbitrary labels) must be listed on *SI* records. However, alternatively, with the time series data read by *HydSeries* from a *SIM* FLO input file (INFILE option 1), control point identifiers are read from the FLO file, and *SI* records are not used.

Beginning and ending years YRBEG and YREND are specified on the *HS* record. Although 1900-2018 observed flows are included in the original input DSS file of Table 2.10, only the flows from January 1940 through December 2017 are read.

### Statistical Analysis STAT Options

The HIN file of Table 2.13 and revisions thereto are employed to analyze the data from the DSS records of Table 2.10. Alternative *HydSeries* statistical analysis options specified by STAT in *HS* record field 12 are applied to time series specified by SERIES in *HS* record field 13 (Table 2.1). The HIN file includes an *SI* record (Table 2.2) with identifiers NAT (naturalized flows) and USGS (observed flows) that comprise DSS pathname part B of the records in the input file Waco.DSS. The statistical analysis results are recorded in the HOT output file.

Table 2.13  
*HYD* Input HIN File with STAT Option 1 and SERIES Option 1

```

**          1          2          3          4          5
**345678901234567890123456789012345678901234567890123456
HS  1940      2017    4    0          IN          0    0    1    1
SI      2      NAT    USGS
ED

```

The HIN file reproduced as Table 2.13 activates STAT option 1 and SERIES option 1, meaning basic statistics are computed for the monthly time series. The results are recorded in the HOT file reproduced as Table 2.14. *HydSeries* was executed with alternative combinations of STAT and SERIES options to obtain the results presented in Tables 2.14 through 2.20.

The results of applying STAT options 1, 2, 3, and 4 to the monthly datasets (SERIES option 1) are presented as Tables 2.14, 2.15, 2.16, and 2.17, respectively. These tables replicate the output HOT files for four executions of program *HYD* with STAT changed on the *HS* record for each execution. STAT option 1 (Table 2.14) includes the mean, standard deviation, and range for each of the two 1949-2017 monthly data sequences. The STAT option 2 regression analysis of Table 2.15 is discussed later in this chapter. Option 3 (Table 2.16) tabulates the mean flow in acre-feet/month for each of the 12 months of the year for each of the two time series.

STAT option 4 creates a monthly table in the HOT file in the format illustrated by Table 2.17 if SERIES option 1 is selected. The entire monthly dataset is tabulated. The annual table illustrated by Table 2.18 is created by STAT option 4 for SERIES options 2, 3, 4, and 5. The annual table includes the annual quantity for each year, the minimum and maximum monthly quantities in each year, and the month in which the minimum monthly and maximum monthly quantities occurred. The monthly and annual tables in the HOT file include a line of data for each year. Tables 2.17 and 2.18 omit most of the years for purposes of brevity.

**Table 2.14**  
**HYD Output HOT File for 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**  
**HYD Output HOT File for 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**  
**HYD Output HOT File for 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

**Table 2.17**  
**HYD Output HOT File for STAT Option 4 and SERIES Option 1**

HYD OUTPUT HOT FILE

Site	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NAT	1940	13511.0	8751.0	6311.0	101058.0	122519.0	451522.0	168538.0	255025.0	72277.0	13015.0	416155.0	405857.0
NAT	1941	133251.0	492000.0	318981.0	508670.0	1597861.0	889095.0	311899.0	289184.0	115304.0	696350.0	238298.0	56767.0
NAT	1942	70132.0	31336.0	29147.0	1401100.0	670494.0	579811.0	51907.0	55723.0	358139.0	527354.0	105937.0	71104.0
NAT	1943	44340.0	31851.0	73147.0	110754.0	89262.0	95298.0	17695.0	5540.0	32245.0	15965.0	5048.0	9192.0
NAT	1944	35857.0	124744.0	159193.0	105126.0	799391.0	129965.0	53302.0	18829.0	68051.0	63554.0	29701.0	55540.0
NAT	1945	169336.0	293601.0	623968.0	921067.0	164507.0	169682.0	385705.0	37233.0	19884.0	190258.0	34980.0	44715.0
NAT	1946	94816.0	181795.0	211690.0	91267.0	250528.0	150689.0	24717.0	58841.0	251697.0	149131.0	199340.0	226418.0

Naturalized (NAT) flows for years 1947 through 2008 are omitted here to shorten this tabulation.

NAT	2009	9546.0	17315.0	71145.0	66072.0	43927.0	33084.0	17606.0	15552.0	95858.0	598449.0	109068.0	63701.0
NAT	2010	312067.0	406679.0	316925.0	411008.0	189348.0	74515.0	158310.0	33868.0	386606.0	48907.0	22073.0	20814.0
NAT	2011	28336.0	35770.0	22993.0	28874.0	15126.0	1055.0	0.0	3643.0	3563.0	81510.0	10221.0	36905.0
NAT	2012	368637.0	166415.0	503434.0	66252.0	16714.0	28908.0	0.0	849.0	19025.0	12665.0	4259.0	1551.0
NAT	2013	45189.0	7498.0	18808.0	22593.0	13162.0	18946.0	47622.0	3772.0	16852.0	69642.0	17354.0	34102.0
NAT	2014	10484.0	11825.0	9879.0	7290.0	52271.0	186584.0	17610.0	1265.0	19921.0	16982.0	8430.0	8335.0
NAT	2015	24349.0	14560.0	72615.0	185246.0	1737694.0	720203.0	248758.0	27155.0	10237.0	469184.0	829174.0	576933.0
NAT	2016	31274.0	12638.0	35700.0	544650.0	1170718.0	291539.0	24418.0	168457.0	477449.0	90322.0	161975.0	53785.0
NAT	2017	47260.0	93996.0	37057.0	36131.0	122957.0	322253.0	71428.0	204158.0	313909.0	41320.0	19262.0	25096.0

USGS	1940	3911.4	8727.3	6573.2	98707.4	120388.8	447859.8	166201.0	249766.6	71700.5	12047.6	411838.0	405758.7
USGS	1941	132823.1	491801.7	284747.1	323172.9	1292747.1	882922.3	206415.9	201346.1	103797.0	735746.8	263660.8	46357.7
USGS	1942	78194.4	25999.3	21947.1	1337137.2	666247.9	569672.8	51290.6	48113.1	323248.2	531492.9	105477.0	72914.4
USGS	1943	65724.3	80727.3	118988.4	125811.6	104509.1	71789.8	56788.8	44098.5	35682.6	16897.2	6876.7	11028.1
USGS	1944	39167.6	123935.2	122213.6	87500.8	758221.5	92717.4	33853.9	26679.7	53760.0	29101.5	38084.6	66862.8
USGS	1945	182691.6	306093.2	556780.2	857633.1	167266.1	165734.9	288702.2	59569.6	29815.5	115801.0	36777.5	58161.3

Observed (USGS) flows for years 1946 through 2011 are omitted to shorten this tabulation.

USGS	2012	36840.6	83936.5	363248.9	134118.3	13639.3	17756.4	22623.5	34068.1	61152.4	12097.8	3366.5	6300.7
USGS	2013	24668.4	4209.9	10582.4	5637.8	9782.5	10417.6	17445.0	4218.4	7998.2	39299.0	10329.9	9750.1
USGS	2014	6536.9	5723.1	15406.2	5114.4	19860.1	36385.2	13765.7	10384.3	18472.5	6647.2	4823.6	2591.2
USGS	2015	7397.6	2894.5	20047.3	38209.6	486938.2	1290188.4	412002.7	32807.4	22697.1	222342.8	473109.4	882228.1
USGS	2016	352825.8	127196.0	446386.1	373432.1	910195.1	1283603.2	421253.6	131422.8	75479.0	31711.7	85656.2	62029.1
USGS	2017	86717.4	97404.3	106006.6	226653.2	20235.4	120850.9	94359.7	25714.1	4438.0	15543.7	5089.0	5554.9

**Table 2.18**  
**HYD Output HOT File for STAT Option 4 and SERIES Option 2**

#### HYD OUTPUT HOT FILE

#### Annual Series for SERIES Option 2 and STAT Option 4

Site	Year	Quantity	Minimum	Maximum	Min	Month	Max	Month
NAT	1940	2034539.00	6311.00	451522.00	3			6
NAT	1941	5647660.00	56767.00	1597861.00	12			5
NAT	1942	3952184.00	29147.00	1401100.00	3			4
NAT	1943	530337.00	5048.00	110754.00	11			4
NAT	1944	1643253.00	18829.00	799391.00	8			5
NAT	1945	3054936.00	19884.00	921067.00	9			4
NAT	1946	1890929.00	24717.00	251697.00	7			9
NAT	1947	1349834.00	11410.00	533060.00	8			5
NAT	1948	803997.00	7324.00	169895.00	12			7
NAT	1949	1663146.00	9058.00	711815.00	8			5
NAT	1950	1343758.00	7937.00	264857.00	12			7
NAT	1951	604241.00	2807.00	290951.00	1			6
NAT	1952	474674.00	2679.00	181202.00	1			5
NAT	1953	1177981.00	658.00	346687.00	6			5
NAT	1954	786410.00	339.00	435691.00	12			5
NAT	1955	1732498.00	1612.00	530893.00	1			10
NAT	1956	465716.00	1858.00	260403.00	7			5
NAT	1957	6613671.00	3483.00	3376485.00	1			5
NAT	1958	1861934.00	10802.00	766686.00	11			5

Naturalized (NAT) flows for years 1959 through 2011 are omitted.

NAT	2012	1188709.00	0.00	503434.00	7			3
NAT	2013	315540.00	3772.00	69642.00	8			10
NAT	2014	350876.00	1265.00	186584.00	8			6
NAT	2015	4916108.00	10237.00	1737694.00	9			5
NAT	2016	3062925.00	12638.00	1170718.00	2			5
NAT	2017	1334827.00	19262.00	322253.00	11			6
USGS	1940	2003480.25	3911.41	447859.84	1			6
USGS	1941	4965538.50	46357.69	1292747.12	12			5
USGS	1942	3831735.00	21947.11	1337137.25	3			4
USGS	1943	738922.25	6876.69	125811.57	11			4
USGS	1944	1472098.50	26679.67	758221.50	8			5
USGS	1945	2825026.00	29815.54	857633.06	9			4
USGS	1946	1808219.50	36547.44	240971.91	7			5

Observed (USGS) flows for years 1947 through 2012 are omitted.

USGS	2013	154339.41	4209.92	39299.03	2			10
USGS	2014	145710.36	2591.21	36385.19	12			6
USGS	2015	3890863.00	2894.48	1290188.38	2			6
USGS	2016	4301190.50	31711.74	1283603.25	10			6
USGS	2017	808567.19	4438.02	226653.22	9			4

## **Regression Trend Analysis of Observed and Naturalized Flows**

Time series plots and regression metrics presented earlier in this chapter indicate that precipitation and evaporation appear to have remained essentially stationary during the 1940-2017 hydrologic period-of-analysis. The graphical analyses of observed and naturalized flows presented earlier and the following linear regression trend analyses investigate the stationarity (homogeneity or stability over time) of river flow characteristics.

Naturalized flows were developed by adjusting observed flows to remove the effects of major dams, water supply diversions, and return flows [12]. Consideration of the effects on river flows of all human activities in a large river basin is not feasible. Flow naturalization procedures focus on water development/use activities with the greatest impact, while also considering the availability of data needed for the flow adjustments. Observed flows can conceptually be expected to exhibit non-stationary (long-term changes) resulting from population and economic growth and associated water resources development over time. River flows observed at gages are converted to naturalized flows for a WAM that are stationary representations of homogenous natural conditions without the effects of the water development, management, allocation, and use modeled by the water rights information in the *SIM* simulation input DAT file.

Linear least-squares regression is based on Equations 2.1, 2.2, and 2.3 discussed on page 16. Equation 2.1 from page 16 is copied below. For the present analysis, the quantity  $E(Y|x)$  computed by Eq. 2.1 is the expected value of the stream flow rate ( $Y$ ) at a given point in time ( $x$ ) in units of acre-feet/month for a monthly series or acre-feet/year for an annual series. The y-intercept " $a$ " is the expected value of the flow rate at the beginning of January 1940. The slope " $b$ " is the change in the flow rate over time in units of acre-feet/month per month for a monthly series or acre-feet/year per year for an annual series (change in rate=volume/time over time).

$$E(Y|x) = a + bx \quad (2.1)$$

A positive slope ( $b$ ) is an indication that the mean (average or expected value) of the flow rate is increasing. A negative slope is an indication of a decrease over time. A slope of zero or closeness to a slope of zero is an indication of stationarity. A regression slope ( $b$ ) of zero is visualized as a horizontal straight line plot of a constant flow rate equal to the y-intercept " $a$ ".

River regulation and water resources development, management, and use affects high flows, median flows, and low flows differently. Thus, regression analysis is applied as follows to eight different time series defined by the SERIES option selected in *HS* record field 13.

SERIES option 1: 1940-2017 monthly observed and naturalized flows in acre-feet/month.

SERIES option 2: 1940-2017 annual observed and naturalized flows in acre-feet/year.

SERIES option 4: 1940-2017 annual series composed of the minimum monthly observed and naturalized flow in acre-feet/month in each year.

SERIES option 5: 1940-2017 annual series composed of the maximum monthly observed and naturalized flow in acre-feet/month in each year.

SERIES option 3 rather than option 2 would be adopted if mean annual flows in cfs are adopted rather than annual flow volumes in acre-feet/year. SERIES options 4 and 5 can also be applied with moving averages rather than the single-month minima or maxima.

Execution of program *HYD* with the input HIN file of Table 2.19 results in the output HOT file of Table 2.20. The regression analysis is applied to 1940-2017 monthly naturalized (NAT) and observed (USGS) flows. With the *HS* record SERIES option changed from 2 to 1, the regression analysis is applied to the 1940-2017 annual naturalized and observed flows with the results tabulated in the HOT file of Table 2.15. Regression results from Table 2.15 (SERIES option 1) and Table 2.20 (SERIES option 2) along with results for SERIES options 4 and 5 are tabulated in Table 2.21.

Table 2.19  
*HYD* Input HIN File with STAT Option 2 and SERIES Option 2

```

**          1          2          3          4          5
**345678901234567890123456789012345678901234567890123456
HS  1940      2017    4    0          IN          0    0    2    2
SI      2      NAT    USGS
ED

```

Table 2.20  
*HYD* Output HOT File for STAT Option 2 and SERIES Option 2

```

HYD OUTPUT HOT FILE
Linear Regression Analysis (STAT=2)
Regression Coefficients for Annual Totals (SERIES Option 2)
Site          Mean  Intercept      Slope      Intercept      Slope
              % Mean  % Mean
NAT          1861228.5 1938316.8 -1951.59973  104.1418  -0.10486
USGS         1638181.6 1770802.2 -3357.48438  108.0956  -0.20495
Averages     1749705.0 1854559.5 -2654.54199  106.1187  -0.15490

```

Table 2.21  
Regression Analysis (STAT Option 2) Results for and SERIES Options 1, 2, 4, and 5

1	2	3	4	5	6	7
SERIES Option	Time Series Identifier	Mean (acre-feet/p)	Intercept (acre-feet/p)	Slope (acre-feet/p)	Intercept (% of mean)	Slope (% of mean)
1 monthly	NAT	155,102	161,986	-14.6924	104.438	-0.00947
1 monthly	USGS	136,515	147,947	-24.4020	108.374	-0.01787
2 annual	NAT	1,861,229	1,938,317	-1,951.60	104.142	-0.10486
2 annual	USGS	1,638,182	1,770,802	-3,357.48	108.096	-0.20495
4 minimum	NAT	11,556	14,806	-82.2921	128.129	-0.71214
4 minimum	USGS	20,161	25,108	-125.231	124.536	-0.62116
5 maximum	NAT	630,228	669,538	-995.169	106.237	-0.15791
5 maximum	USGS	527,751	619,406	-1,063.314	107.966	-0.20166

Table 2.21 summarizes the results of applying regression analysis to naturalized (NAT) and observed (USGS) flows covering a 1940-2017 period-of-analysis (936 months or 78 years). The third column of Table 2.21 is the arithmetic average of the following quantities as defined for the alternative time series.

- Mean of 936 monthly flows in units of acre-feet/month for SERIES option 1.
- Mean of 78 annual flows in units of acre-feet/year for SERIES option 2.
- Mean of 78 quantities consisting of the minimum monthly flow in units of acre-feet/month during each of the 78 years for SERIES option 4.
- Mean of 78 quantities consisting of maximum monthly flow in units of acre-feet/month during each of the 78 years for SERIES option 5.

The fourth and fifth columns of Table 2.21 are the y-intercept (a) and slope (b) of Equation 2.1. The intercept has units of acre-feet/month for SERIES options 1, 4, and 5 and acre-feet/year for SERIES option 2. The slope has units of [(acre-feet/month) per month] for SERIES options 1, 4, and 5 and [(acre-feet/year) per year] for SERIES option 2. Columns 6 and 7 of Table 2.21 are the intercept and slope from columns 4 and 5 expressed as a percentage of the mean in column 3.

An intercept (column 4) equal to the mean (column 3) and slope (columns 5 and 7) of zero would be an indication of no trend or perfect stationarity during 1940-2017 for the time series. The slopes for the eight 1940-2017 time series in Table 2.21 are small negative numbers indicating decreasing flow. The slopes are near zero and vary with different sub-periods of the 1940-2017 period-of-analysis. Any trends or long-term changes that may have occurred during 1940-2017 are hidden in the great continuous flow variability and are not readily apparent.

### **Summary of HydSeries Capabilities**

*HydSeries* (hydrologic series) is a subprogram of the WRAP program *HYD* that can be used either in combination with or independently of the other *HYD* capabilities covered in Chapters 3 through 8 of this *Hydrology Manual*. The programs *HYD*, *SIM*, *SIMD*, *TABLES*, and *HEC-DSSVue* are an interconnected data management and analysis system that can be employed individually or in combination to perform various tasks. *HydSeries* is designed primarily to be used with *HEC-DSSVue* and other components of *HYD* to develop monthly hydrology input datasets for the simulation models *SIM* and *SIMD*. *HydSeries* and *HEC-DSSVue* can also be applied with *TABLES* in the analysis of *SIM/SIMD* simulation results.

*HydSeries* reads a dataset consisting of any number of monthly time series of continuous data for each month of a period-of-analysis covering any number of years. The following time series data management and analysis capabilities are provided.

- Conversions between file 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.

### File Conversions

DSS files can be converted to text files. Text files can be converted to DSS files. Record organization and format can be changed. Time series data files are read by *HydSeries* in various alternative formats as specified by parameters INFILE, INEXT, and INID entered on a HIN file *HS* record. The time series are recorded in a *HydSeries* output file defined by OUTFILE, OUTEXT, and OUTID. *HydSeries* can be employed with essentially any monthly time series variables. Any monthly data can be read from a DSS input file. Monthly or annual series can be written to a DSS file created by *HydSeries*. *SIM* input FLO files of *IN* record naturalized flows, EVA files of *EV* record evaporation-precipitation depths, or TSF files of *TS* record target series can be read or created with *HydSeries*. A columnar format option facilitates connecting with Microsoft Excel spreadsheets. *HydSeries* can read any of the *SIM* simulation results variables or modifications thereto from a DSS file or TOU file created with the *TABLES* time series routines.

### Texas Water Development Board (TWDB) Evaporation and Precipitation Datasets

The *HS* record PE, SSI, and INFILE options control features that facilitate convenient access to and analysis of databases maintained by the TWDB of monthly evaporation and precipitation for 168 quadrangles encompassing Texas and surrounding area. These datasets have been converted to text (.txt) and DSS files available with the WRAP software. The files Evaporation.EEE and Precipitation.PPP can be read with Microsoft Excel or other editors as well as by *HydSeries*. The file PrecipEvap.DSS contains the same TWDB monthly precipitation and evaporation data as the PPP and EEE files and can be read by either *HEC-DSSVue* or *HydSeries*. Any of the *HydSeries* analysis capabilities can be applied to these time series.

### Annual Time Series

*HS* record option selection parameter SERIES controls creation of annual series from the monthly series read as input. The default option 1 is to work only with the monthly series. SERIES options 2 and 3 compute annual totals or annual means. Options 4 and 5 create an annual series of minimum or maximum values of MA-month moving averages in each year. The default MA of one month results in an annual series of the minimum or maximum monthly flow in each year. Any integer between 1 and 12 can be entered for MA for the moving average computations. Options 4 and 5 facilitate focusing analyses on either low flows or high flows.

### Basic Statistics

*HydSeries* includes STAT options for creating summary tables of means, standard deviations, and ranges and other structured tabulations. *HEC-DSSVue* and the WRAP program *TABLES* provide flexible capabilities for performing frequency analyses for any time series dataset read from a DSS file including DSS files created with *HydSeries*.

### Linear Regression Trend Analysis

The stationarity (homogeneity over time) or lack thereof of any of the *HydSeries* time series can be investigated by graphical analyses of *HEC-DSSVue* time series plots and regression metrics computed by *HydSeries* regression analyses activated by STAT option 2.

### CHAPTER 3

## DEVELOPMENT OF NATURALIZED FLOW AND EVAPORATION-PRECIPITATION DATASETS

Whereas Chapters 4, 5, and 6 deal with updating or modifying existing datasets, options covered in Chapter 3 were originally designed for creating new datasets. Chapter 3 covers capabilities incorporated in *HYD* for creating FLO and EVA files or a DSS file for inclusion in *SIM* input datasets. *HYD* input records for applying these capabilities are described in Chapter 7.

### Dataset Creation Capabilities Provided by *HYD*

The WRAP program *HYD* is a set of computational and data organization options designed to facilitate developing datasets of naturalized stream flows and net evaporation-precipitation rates. Data may be simply read from a *HYD* input file and written to a *HYD* output file with no adjustments other than changing the organization and/or format of the dataset. Alternatively, the data may undergo a variety of adjustments and manipulations employing the various computational options of *HYD* outlined in Tables 3.1 and 3.2 and discussed in the following paragraphs. The tasks are listed in Tables 3.1 and 3.2 generally in the order in which they are performed within *HYD*. All tasks are optional. The model-user specifies any number of tasks to be performed in a particular execution of *HYD* through entries on the *JC*, *CP*, *EP*, *AN*, *AS*, *RS* and *EQ* input records. Table 3.1 notes the records that are used to activate each of the *HYD* capabilities outlined in Table 3.2.

A single execution of *HYD* may include any number of data adjustments. Alternatively, in order to sequence the adjustments certain ways, multiple runs may be made with the output file from one run being read as the input file for the next. Files may also be transported back and forth between *HYD* and spreadsheet programs or DSS. Many of the computations performed by *HYD* are also adaptable to *HEC-DSSVue* or spreadsheet programs.

The various *HYD* options involve reading data from *HYD* input files and performing computations to create stream flow and/or evaporation-precipitation datasets consisting of *IN* and *EV* records stored in new files with filename extensions FLO and EVA or in a new DSS file. *HYD* options also include developing several tables of other related information. In addition to supplemental information noted in later chapters, the features covered in Chapter 3 include options for storing the following auxiliary information in a *HYD* output file with filename extension HOT.

- watershed parameters from a DIS file as specified by JC(10)
- negative incremental flow adjustments as specified by NEGINC on the *JC* record
- component parts of reservoir adjustments as specified by JC(11) on the *JC* record and parameter RS(6) on one or more individual *RS* records

### Initial Data Manipulations

The following optional initial tasks are activated by parameters entered on *XL*, *CP*, and *MF* records described in Chapter 7.

- The flows and/or evaporation-precipitation rates are multiplied by factors specified on *XL*, *CP*, and *MF* records. The monthly factors on *MF* records may also be added.

- Stream flows and/or evaporation-precipitation rates may be assigned to a control point by either verbatim repeating data from another control point or by multiplying the repeated flows by the factors from the *CP* records.

The *XL* and *CP* record factors in *HYD* are essentially the same as the factors in *SIM* covered in Chapter 3 of the *Users Manual*. The factors may be used for unit conversions, such as converting stream flows from second-feet-day ( $\text{ft}^3/\text{s} \times \text{day}$ ) to acre-feet or net evaporation-precipitation depths from inches to feet. Also, the same stream flow or evaporation-precipitation rates may be conveniently assigned to multiple control points as appropriate. Drainage area ratios may be applied to transfer flows from gaged to ungaged sites. These data adjustments occurring immediately after the original data are read are then followed by the other optional tasks listed in Table 3.2.

Table 3.1  
Activating *HYD* Capabilities

<u>Optional Capability</u>	<u>Activation Switch</u>
• <u>Initial Data Manipulations</u>	
1. Multiplying by factors on <i>XL</i> , <i>CP</i> , or <i>MF</i> records. or adding factors from <i>MF</i> records.	<i>CP</i> record fields 4 and 5 <i>MF</i> and <i>XL</i> records
2. Repeating data at multiple control points.	<i>CP</i> record fields 7 and 8
• <u>Representative Annual Set of Monthly Data</u>	
3. Methods for assigning sets of 12 monthly values.	<i>AN</i> record
• <u>Developing Sets of Net Evaporation-Precipitation Rates (EV Records)</u>	
4. Subtracting precipitation from evaporation.	<i>EP</i> record
5. Averaging data sets.	<i>EP</i> record
6. Applying the equation: $E_{\text{adjusted}} = a E^b + c$	<i>EQ</i> record
• <u>Developing Sets of Naturalized Stream Flows (IN Records)</u>	
7. Adding adjustments.	<i>JC</i> field 7, <i>AS</i> record
8. Reservoir adjustments.	<i>AS</i> followed by <i>RS</i> record
9. Applying the equation: $Q_{\text{adjusted}} = a Q^b + c$	<i>EQ</i> record
10. Flow distribution.	<i>JC</i> field 11 and <i>CP</i> field 6
11. Negative incremental flow adjustments.	<i>JC</i> record fields 16 & 17
• <u>Changing the Organization and Format of the Datasets</u>	
12. Grouping by control points versus years.	<i>JC</i> record fields 5,6,12,13
13. Converting from old <i>HYD</i> file format.	<i>JC</i> record fields 5,6,12,13
14. Converting between text and <i>DSS</i> files.	<i>JC</i> record fields 5,6,12,13
15. Converting between a table in columnar format.	<i>JC</i> record fields 5,6,12,13
16. <i>SIM</i> simulation results to input record format.	<i>OI</i> record (Chapters 3 and 4)

Table 3.2  
Capabilities Provided by *HYD*

- 
- *Initial Manipulations of Stream Flows and Evaporation-Precipitation Depths*
    1. Multiplying the original data by constants specified on *XL* or *CP* records or multiplying or adding monthly-varying factors from *MF* records.
    2. Assigning flows or net evaporation-precipitation rates to a control point by either verbatim repeating data from another control point or by multiplying the repeated flows by the factors from the *CP* records.
  - *Annual Set of Monthly Flow Volumes or Evaporation-Precipitation Depths*
    3. Sets of 12 monthly volumes or depths for control points may be determined by computing means or assigning a specified exceedance frequency.
  - *Developing Sets of Net Evaporation-Precipitation Depths (EV Records)*
    4. Subtracting precipitation depths from evaporation depths to obtain net evaporation-precipitation depths.
    5. Developing net evaporation-precipitation depths for a particular control point as a weighted average of values from two, three, or four other data sets.
    6. Adjusting evaporation-precipitation depths (*E*) using the equation:  $E_{\text{adjusted}} = a E^b + c$
  - *Developing Sets of Naturalized or Otherwise Adjusted Stream Flows (IN Records)*
    7. Adding or subtracting sets of adjustments to stream flows associated with historical water supply diversions and return flows, reservoir storage and evaporation, *SIM* simulation results, and other factors that may be pertinent.
    8. Developing adjustments for the historical effects of reservoir storage and net evaporation-precipitation.
    9. Applying the equations:  $Q_{\text{adjusted}} = a Q^b + c$  or  $\Delta Q_{\text{adjustment}} = (a Q^b + c) - Q$
    10. Distributing flows from gaged (known flow) to ungaged (unknown flow) locations.
    11. Adjusting stream flows to prevent incremental flows from being negative.
  - *Changing the Organization and Format of the Datasets*
    12. Converting the format of the *FLO* and *EVA* files between records grouped by control points versus records grouped by years.
    13. Converting an *HYD* file in an old format to *FLO* and *EVA* files in standard format.
    14. Converting between *FLO* and *EVA* text files and *DSS* binary files.
    15. Converting flows and evaporation-precipitation depths to a columnar format, and vice versa, to interchange with Microsoft Excel or other programs.
    16. Converting *SIM* simulation results to *SIM/HYD* input record format (Chapters 3 and 4).
-

### Changing the Organization and Format of the Datasets

*HYD* reads text-format or DSS input files near the beginning of program execution before the data handling and computational tasks and writes to output files near the end. The organization and format for the output files may be different than that of the input files. Datasets may also be converted between text files and DSS files and between *SIM/HYD* files and Microsoft Excel spreadsheet files. Text files may be reorganized. Options listed in Table 3.2 allow reading input files in alternative formats and converting to another selected format. The alternative formats are further discussed in later in this chapter.

### **HYD Features for Developing Evaporation-Precipitation Datasets**

*HYD* includes an option controlled by the *EP* record to perform the following arithmetic operations on two, three, or four arrays of numbers.

1. Each array is altered by multiplying each element by a user-specified constant, which may be positive or negative depending on the application. The default multiplier is 1.0.
2. The arrays are combined by adding corresponding elements.

This option is designed to combine sets of reservoir evaporation, precipitation, and/or net evaporation minus precipitation rates (depth/month) to develop sets of *EV* records for input to *SIM*.

Typical applications of this feature include:

- subtracting precipitation rates from evaporation rates to obtain net evaporation-precipitation rates (depth/month)
- developing net evaporation-precipitation rates (depth/month) for a particular control point as a weighted average of values from multiple data sets

The first application consists of simply subtracting a set of precipitation depths from concurrent evaporation depths to obtain net evaporation-precipitation depths. The second application involves determining evaporation-precipitation rates for a control point as a weighted average of values from two to four other data sets. *HYD* multiplies the different sets of data by user-specified weighting-factors and sums the products. As discussed in Chapter 2, the Texas Water Development Board (TWDB) maintains precipitation and reservoir evaporation databases based on a grid of quadrangles covering the state. This *HYD* option is designed to determine values for a control point as a weighed-average of data from two, three, or four adjoining quadrangles.

### **Regression Equation to Adjust Flows and/or Evaporation-Precipitation Depths**

The monthly stream flows ( $Q_{\text{adjusted}}$ ) and evaporation-precipitation depths ( $E_{\text{adjusted}}$ ) at a control point may be computed by applying the following equations to the quantities ( $Q$  or  $E$ ) at the same control point or a different control point.

$$Q_{\text{adjusted}} = a Q^b + c \quad \text{and/or} \quad E_{\text{adjusted}} = a E^b + c \quad (3.1)$$

The  $Q$  equation coefficients  $a$ ,  $b$ , and  $c$  and  $E$  equation coefficients  $a$ ,  $b$ , and  $c$  for particular control points or groups of control points are entered on *EQ* records.

The second equation converts the evaporation-precipitation depth  $E$  at a specified control point to an adjusted value  $E_{\text{adjusted}}$ , without considering other control points. The  $Q$  equation may also be applied directly to a specified control point without considering flows at downstream locations. However, alternatively, an incremental  $Q$  adjustment may be cascaded downstream. The incremental  $Q$  adjustment is computed as:

$$\Delta Q_{\text{adjustment}} = (a Q^b + c) - Q \quad (3.2)$$

$\Delta Q_{\text{adjustment}}$  is treated like any other adjustment to be added to the flows. It may be cascaded downstream with channel losses and with additions to the flows at downstream control points.

The regression equation feature may be used in various ways. It was initially incorporated into *HYD* for use with a precipitation-runoff watershed simulation model such as the *Soil and Water Assessment Tool (SWAT)* developed at the USDA Agricultural Research Service and Texas Agricultural Experiment Station Research Center in Temple, Texas. The precipitation-runoff model may be used to quantify the effects of watershed land use changes. *SWAT* and *WRAP* have also been applied in combination on a research project assessing the impacts of climate change on water management. Stream flow is computed with *SWAT* for given precipitation and other climatic data and watershed characteristics. Changes in land use are modeled by changing watershed parameter values. Changes in climate are reflected in precipitation, temperature, and other climatic variables. The precipitation-runoff model is applied to compute stream flows for scenarios with and without climate or watershed changes. Regression analyses are then applied to flows computed with the two different scenarios to obtain a set of  $a$ ,  $b$ ,  $c$  coefficients for input to *WRAP-HYD*.

As discussed in *Reference Manual* Chapter 3, regression equations may be used to distribute flows from gaged to ungaged locations. Other applications are also possible.

### **HYD Features for Developing Stream Flow Datasets**

The following *HYD* capabilities are provided to facilitate developing the monthly flow volumes which are input to *SIM* as *IN* records in a FLO file or DSS records in a DSS file.

1. adding or subtracting sets of adjustments to flows with the flow adjustments being obtained from various sources and optionally cascading downstream
2. developing flow adjustments for the historical effects of reservoirs
3. applying the equations:  $Q_{\text{adjusted}} = a Q^b + c$  or  $\Delta Q_{\text{adjustment}} = (a Q^b + c) - Q$
4. distributing flows from gaged (known flow) to ungaged (unknown flow) locations
5. adjusting stream flows to prevent incremental flows from being negative

*HYD* provides a flexible generic set of options to facilitate adjusting stream flows to reflect changes in river basin development. The most typical application is converting historical stream flows to naturalized flows. However, conversions between other scenarios of river system development may also be of interest. *HYD* is designed to be flexible for applications such as those discussed in other chapters as well as modeling natural flows which is the focus of Chapter 3. Manipulation of flow data may involve combined use of *HYD*, Microsoft Excel, and *HEC-DSSVue*.

### Stream Flow Naturalization Adjustments

Naturalized stream flows are gaged flows adjusted to remove the effects of human water management and use. *HYD* has options for modifying stream flows by adding or subtracting any number of data sets of flow adjustments. Typically, the original unadjusted stream flows will be historical gaged flows. Typical adjustments include historical water supply diversions, return flows from surface and/or groundwater diversions, reservoir storage changes, and reservoir surface evaporation/precipitation. Other types of adjustments may be added or subtracted as well. For example, changes in spring flows or stream base flows determined with a groundwater model and associated with alternative aquifer management strategies may be treated as adjustments to naturalized stream flows.

The adjustment data sets are simply time series of numbers to be added to the stream flows. The flow adjustments may be positive, negative, or zero. An option allows an adjustment data set to be multiplied by a user-specified factor prior to being added to the flows. Any number of sets of adjustments may be applied at a particular control point. The data sets are added at a specified control point and optionally at all downstream control points. If the channel loss factor field of the control point *CP* record is non-zero, channel losses are reflected in cascading the adjustments downstream. Options are provided for setting the final adjusted flows to zero if the computations result in negative values. Particular adjustments may cover all or any portion of the hydrologic period-of-analysis.

The adjustments to be combined with the stream flows may consist of either constant annual sequences of 12 monthly values or longer multiple-year time series. Adjustments for the effects of reservoirs are computed within *HYD* and then handled the same as the other adjustments read from input files. The following types of sets of adjustments may be added to the stream flows.

1. A constant may be entered on the *AS* record to add to the flows.
2. A set of 12 adjustments for each of the 12 months of the year to be repeated annually during a specified span of years are input on constant inflow *CI* records.
3. Multiple-year time series of adjustments are entered on flow adjustment *FA* records.
4. Variables read from the *SIM* output file may serve as flows and flow adjustments.
5. Adjustments for the effects of reservoirs may be computed within *HYD*.

All five types of adjustments are handled the same. An adjustment specification *AS* record provides the following information for each set of adjustments.

- control point identifier
- beginning and ending year of adjustments
- source of adjustments
- whether adjustments are to be applied to all downstream control points
- factor by which adjustments are multiplied
- selection of option for dealing with possibility of negative stream flows

Adjustments may result in negative stream flows. Options are available to either maintain the negative flows as the adjustments accumulate or set them equal to zero. For multiple sets of adjustments, the negative values in the cumulatively adjusted stream flows may be set to zero after any specified adjustment. If negative flows are changed to zero, an option allows flow in the next month to be decreased by the amount of the negative flow. Another option limits the adjustment to the amount of stream flow. For example, if an adjustment of 25 acre-feet/month is to be subtracted from a stream flow of 15 acre-feet/month, the adjustment is changed to 15 acre-feet/month. The 15 acre-feet (not 25 acre-feet) adjustment is applied at each control point as the adjustment cascades downstream.

### Stream Flow Adjustments for the Effects of Reservoirs

Input data required to compute adjustments for the effects of reservoirs on stream flow include historical end-of-month storage content (*SC* records) and storage-area relationships (*SV/SA* or *RS* records), and net evaporation-precipitation rates (*EV* records). The adjustments include the following user-specified component parts that are combined to obtain a total adjustment that is applied to the flows at the control of the reservoir and optionally at downstream control points.

- increases in reservoir storage content  
(*RS* record field 3; default: adjustment to be added to stream flows)
- decreases in conservation storage content  
(*RS* record field 4; default: adjustment to be subtracted from stream flows)
- decreases in storage above a specified storage capacity which represent spills or flood releases (*RS* field 5; default: adjustment to be subtracted from stream flows)
- net evaporation minus precipitation volumes  
(*RS* record field 6; default: adjustment to be added to stream flows)
- portion of naturalized stream flow representing runoff from land area covered by reservoir that would have occurred without the reservoir  
(*RS* record field 7; default: adjustment to be added to stream flows)

The model-user specifies on the reservoir storage *RS* record which component parts to include in the total adjustment. *HYD* combines the component parts to obtain a total adjustment which is applied just like other flow adjustment *FA* or constant inflow *CI* record adjustments to adjust the stream flows at the control point of the reservoir and optionally at each downstream control point. *RS* record field 8 specifies creation of a table showing the component parts of the monthly reservoir adjustments.

Each component part of the adjustment may be either added to or subtracted from the stream flow, with defaults shown in parentheses in the preceding list. The defaults represent the conventional process of naturalizing gaged flows. However, flexibility is provided to model various situations. For example, water supply diversion data, normally input on flow adjustment *FA* records, may not be available. Decreases in conservation storage is caused by evaporation and downstream releases as well as lakeside diversions. However, if conservation storage decreases are caused primarily by diversions, and diversion data are unavailable and thus not included in the

naturalization process, the decreases in conservation storage may be omitted as partial compensation for the missing *FA* record diversion data.

*HYD* computes net evaporation-precipitation volumes by applying rates (depth/month) to the average water surface area during the month determined by combining storage contents with the storage-area relationship for the reservoir. Net evaporation-precipitation depths are either read from *EV* records or computed as specified by *EP* records based on data read from *EV* records. The format for entering reservoir storage volume versus water surface area relationships is the same in both *HYD* and *SIM*. A storage-area relationship may be provided as either a table on *SV* and *SA* records or as equation coefficients entered on a *RS* record (rather than *SIM WS* record).

As discussed in *Reference Manual* Chapter 3, *HYD* has an option for increasing the naturalized stream flows to account for runoff derived from precipitation falling on dry land that historically was actually covered by the reservoir. The precipitation falling on the reservoir is removed in the flow naturalization process with the net evaporation less precipitation adjustments. The adjustment for the portion of the stream flow representing runoff from the land area covered by a reservoir that would have occurred without the reservoir is incorporated in both *SIM* and *HYD* and is conceptually the same as the drainage area method for transferring flows. The adjustment is computed by multiplying the naturalized stream flow by the ratio of reservoir water surface area to watershed drainage area. Since the current value for naturalized flow at the control point is used, this adjustment should be made after other relevant adjustments.

*JC* record field 17 (*EPADJ*), *CP* record field 9 (*EWA*), and *RS* record field 7 (*RS(5)*) activate this *HYD* option. *RS(5)* specifies whether the site runoff is included in a particular reservoir adjustment. *JC* field 12 sets the default option applied to all control points for which the *CP* field 9 is left blank. An entry for *EWA* on a *CP* record overrides the default option set by *EPADJ* on the *JC* record.

The precipitation-runoff adjustment requires a drainage area. An effective total watershed area may be input as a positive number in *CP* field 9 for use with the total naturalized flows at that control point. Alternatively, the incremental or total watershed area and corresponding incremental or total flows for either the ungaged (*FD* record field 2) or gaged (*FD* field 3) control points may be used by entering a -1 or -2 in *CP* field 9 (for that control point) or *JC* field 17 (default for all control points). Incremental flows and watershed areas determined based on information from the *FD* and *WP* records are identically the same for the rainfall-runoff adjustments as for distributing flows from gaged to ungaged sites.

The increase or decrease in reservoir storage content during each month is computed from the end-of-month storage contents provided on *SC* records. Storage increases, decreases, or both may be included in the adjustment. Storage decreases occurring above and below a specified storage capacity are determined separately. The user-specified storage capacity is typically the full conservation storage. Storage above this capacity represents flood storage, and corresponding storage reductions represent spills or flood releases. Flood control pool spills are shown as a separate column in the table created by *RS* record field 8. With the reservoir storage *RS* record default options, flood spills are handled the same as decreases in conservation pool storage in the final adjustments. However, if water supply diversion data is lacking, conservation pool storage decreases may be omitted to compensate for omissions of diversions in the adjustments.

### Distributing Flows from Gaged to Ungaged Locations

Naturalized flows are typically developed for locations of gaging stations by adjusting the recorded observed flows. Naturalized flows at numerous ungaged sites of water rights are then estimated based on combining the concurrent naturalized flows at gaging stations with parameters characterizing the watersheds above the gaged and ungaged sites. Alternative methods for transferring naturalized flows from gaged (known flow) to ungaged (unknown flow) locations are outlined in Chapter 3 of the *Reference Manual*. These techniques include the drainage area ratio method, a modified version of the NRCS curve number methodology, and other related approaches. Watershed parameters are entered on *FD*, *FC*, and *WP* records in a DIS file. *HYD* includes an option for developing tables displaying the watershed parameters including both values inputted on *WP* records and values for incremental watersheds computed within *HYD*.

The same flow distribution techniques are incorporated in both *HYD* and *SIM*, but the computed flows are stored in different formats. *HYD* stores the flows computed for the ungaged control points as *IN* records along with the original *IN* records for the known-flow control points. *SIM* writes synthesized naturalized flows to its output file just like all the other simulation results. In a typical major river basin application, recorded flows may be used from perhaps 10 to 80 gaging stations. Naturalized flows developed at the gage sites may then be distributed to several other key control points within *HYD* with the results permanently stored as *IN* records in the *HYD* output (*SIM* input) file. Within *SIM*, naturalized flows may be distributed to perhaps several hundred other sites internally without further enlarging the file of *IN* records.

### Negative Incremental Stream Flow Adjustments

Total, rather than incremental, naturalized river flows are provided as *SIM* input. All computational and data handling procedures in *SIM* and *HYD* are based on total flows. Negative incremental stream flows are an indication of complexities that perhaps could cause inaccuracies in the simulation. The incremental local flow at a control point is defined as the total flow at the control point minus the corresponding flow at control point(s) located immediately upstream. Since flows normally increase going downstream, incremental flows are usually positive. However, flows may be greater upstream than downstream for various reasons. *HYD* and *SIM* include options to identify negative incremental flows and adjust the naturalized flows to alleviate negative incrementals. The negative incremental flow adjustments may be written to a file for information.

Options for dealing with negative incremental flows are described in *Reference Manual* Chapter 3. Negative incremental flow options 1, 2, and 3 specified on the *HYD JC* or *SIM JD* records are the same in either program. *HYD* adjusts flows for options 2 and 3. Options 3, 4, and 6 involve the same flow adjustments applied in a different manner by *SIM*. Options 4, 5, 6, 7, and 8 involve computations performed within the *SIM* water rights loop that are not pertinent to *HYD*.

### Data Arrays

Most *HYD* data management and computational operations work with the array *FLOW(cp,yr,month)* containing monthly stream flow volumes (volume/month) and/or the array *EP(cp,yr,month)* containing monthly evaporation rates, precipitation rates, or net evaporation minus precipitation rates (depth/month). The three dimensional arrays are indexed as follows.

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

The control points are sequenced in the order in which the *CP* records are placed in the HIN file. The total number of control points is the number of *CP* records in the HIN file. The arrays hold data for all of the months in the hydrologic period-of-analysis specified in *JC* record fields 2 and 3. The total number of years is defined by *JC* record field 2. There are 12 months in each year.

All elements of the *FLOW* and *EP* arrays are assigned values of zero at the beginning of a *HYD* execution. The arrays are then partially or completely filled with data read by *HYD* from input files in accordance with specifications on the *JC* record. *JC* record parameters also specify the format and organization of the output files to which the arrays are written at the end of the *HYD* execution. Adjustments to the *FLOW* and *EP* arrays during an execution of *HYD* are defined by *CP*, *CI*, *FD*, *EP*, *AN*, *AS*, *RS*, and *EQ* records.

Control point identifiers *CPID(cp,1)* and *CPID(cp,2)* entered in *CP* record fields 2 and 3 are defined as follows.

*CPID(cp,1)* – six-character identifier of the control point  
*CPID(cp,2)* – identifier of the next downstream control point

Computations are performed and the *FLOW* and *EP* array data are written to *HYD* output files in the sequential control point order in which the *CP* records are entered in the HIN file. Flow adjustment specification *AS* record cascading computations require the next downstream control points *CPID(cp,2)* entered on the *CP* records to define spatial connectivity. Other entries on the *CP* record define various adjustments to the *FLOW* and *EP* array data. With the exception of *CPID(cp,1)* in field 2, all *CP* record fields may be blank unless needed to define specific adjustments to the *FLOW* and *EP* arrays. *CP* records are not needed at all if only *OI* record operations (Chapter 4) are being performed.

The arrays in the Fortran code are dimensioned to reserve memory space. The number of control points in the *FLOW* and *EP* arrays is determined automatically by *HYD* by counting the *CP* records. The size of the *SIM* output OUT file arrays is set by parameters read from the fifth line of the OUT file. The number of years is set by *JC* record field 3. The maximum number of reservoir storage/area tables (*SV/SA*) records is set internally at 50. The maximum number of upstream gages on *FD* records is set internally at 20. There are no limits on the number of *CP*, *FD/FC/WP*, *EP*, *OI*, *AN*, *AS*, *FA*, *RS*, *RC*, *CI*, and *EQ* records and associated data adjustments.

### **Organization of *HYD* Operations**

*WRAP-HYD* is designed for flexibility for use in a myriad of ways. A single execution of the program may include any number of data adjustments. Alternatively, in order to sequence the adjustments certain ways, multiple runs may be made with the output file from one run being read as the input file for the next. *HYD* both reads and creates *IN* and *EV* records in both text format (*FLO* and *EVA* files) or as *DSS* records in a *DSS* file. Data stored by *HYD* in *DSS* files can be plotted in *HEC-DSSVue*. Tabular format options in *HYD* facilitate transporting data back and forth between *HYD* and Microsoft Excel or other spreadsheet programs.

Table 3.3  
Sequential Order of *HYD* Operations

- 
1. FLOW and EP arrays are populated with initial data in accordance with JC(1) and JC(2) specifications from the *JC* record. *CP* record CPDT(cp,1) and CPDT(cp,2) factors and monthly *MF* record factors are applied and *CP* record CPIN(cp) and CPEV(cp) operations are performed as data are read from FLO, EVA, HYD, and/or DSS input files to populate the FLOW and EP arrays. These *CP* record operations are not applied if the FLOW and EP arrays are initially populated from the OUT file.
  2. Table 3.1 data from OUT file is stored in memory if specified by JC(1)=7, JC(2)=7, or JC(6)=1,2. OUT file data is written to the HOT file as specified by *OI* records.
  3. *AN* record operations using either FLOW or EP array data develop a representative dataset for a year for use in creating a new dataset or extending the period covered.
  4. *EP* record combining operations using data from the EP array are performed if one or more *EP* records are included in HIN file. Results are stored in the EP array.
  5. The FLOW array data are adjusted in accordance with *AS*, *FA*, *RS*, and *EQ* records if specified by the presence of *AS* and/or *EQ* records. Adjusted flows are stored back in the FLOW array.
  6. Flow distribution operations are performed as specified by *CP* records using information from DIS file *FD*, *FC*, and *WP* records, with synthesized flows recorded in the FLOW array. Flow distribution methods are the same in both *HYD* and *SIM*.
  7. Negative incremental flow adjustment operations are performed with flows in the FLOW array in accordance with *JC* record parameters NEGINC and EPADJ.
  8. The final FLOW and EP arrays with accumulated adjustments are written to output files in formats specified by JC(8), JC(9), and JC(10) from the *JC* record.
- 

All elements of the *FLOW(cp,year,month)* and *EP(cp,year,month)* arrays are set equal to zero at the beginning of a *HYD* execution. The sequence of operations on the values in the *FLOW(cp,year,month)* and *EP(cp,year,month)* arrays are outlined in Table 3.3. All operations are optional. The operations on the arrays are performed in the order listed in Table 3.3. They are also discussed below in the order in which they occur during an execution of *HYD*.

- Files are opened, the HIN file is read, and initial error and warning checks are performed. Optional additional ICHECK option 2 checks of *IN* and *EV* records may be performed. Other checks are performed later as the various operations are performed.
- Data are read as specified by *JC* record parameters from either *IN* and *EV* records in FLO and/or EVA files or a HYD file, records in a DSS file, *SIM* OUT file simulation results, or as columns

in a table in FLO and/or EVA files. These monthly stream flow volumes and monthly evaporation, precipitation, or net evaporation less precipitation depths are assigned to the  $FLOW(cp, year, month)$  and  $EP(cp, year, month)$  arrays. Any array elements not read-in are still zeros. The following operations are based on modifying and outputting the values stored in these two arrays.

- The *AN* record computes statistics for the 12 months of the year from the *FLOW* and/or *EP* arrays which can be used to extend the hydrology to cover additional years for which data are not available.
- Sets of monthly reservoir surface evaporation and/or precipitation depths or monthly net evaporation-precipitation depths are combined as specified by *EP* records to obtain new sets of depth/month values stored in the  $EP(cp, yr, month)$  array. Actually, the arrays combined by addition and subtraction operations to derive the *EP* array can be any sets of numbers.
- Stream flow adjustments are performed as specified by adjustment specification *AS* and/or regression equation *EQ* records. Each *AS* or *EQ* record results in revised values in the  $FLOW(cp, year, month)$  array for the specified control point and optionally downstream control points. The *AS* and/or *EQ* record adjustments are performed in sequential order as each *AS* or *EQ* record is read from the input file. Thus, the order of the *AS* and *EQ* records set the order of the adjustment computations. Any number of *AS* and *EQ* records and resulting adjustments, in any order, may be included in an execution of *HYD*.

Information required to perform *AS* record adjustments is provided by associated *FA*, *CI*, *RS*, and *SC* records or read from a file with filename extension OUT. A reservoir specification *RS* record defines the component parts computed within *HYD* of an adjustment for the effects of a reservoir. The computed component parts may be written to the root2.HOT file as a table for information. The total reservoir adjustment is treated just like any other adjustment of the  $FLOW(cp, year, month)$  array. Any number of reservoirs (*RS* records) may be included in a *HYD* run. All adjustments are performed sequentially in the order that the *AS* records are entered in the input file.

The adjustment equations:

$$Q_{\text{adjusted}} = a Q^b + c$$

$$\Delta Q_{\text{adjustment}} = (a Q^b + c) - Q$$

$$E_{\text{adjusted}} = a E^b + c$$

are applied to the  $FLOW(cp, year, month)$  and  $EP(cp, year, month)$  arrays as specified by *EQ* records with the coefficients *a*, *b*, and *c* read from the *EQ* records. Again, any number of *EQ* records may be included in the data set, with the adjustments being performed in the order that the *EQ* records are read. If both *EQ* and *AS* records are included, they may be intermixed in any order.

- River flows are distributed from gaged (known flow) to ungaged (unknown flow) control points using methods covered in Chapter 3 of the *Reference Manual* as specified by *FD*, *FC*, and *WP* records from the DIS file. Watershed parameter tables may be written to the HOT file for information. The synthesized stream flows are stored in the  $FLOW(cp, year, month)$  array.

- Negative incremental flow adjustments described in Chapter 3 of the *Reference Manual* are performed as specified by *ADJINC* on the *JC* record. The *FLOW(cp,year,month)* array is modified. The adjustments may also be written to the HYD output HOT file as specified by *NEGINC* on the *JC* record.
- The *FLOW(cp,year,month)* and *EP(cp,year,month)* arrays are written to output files as *IN* and *EV* records, DSS records, and/or as tables, as specified by parameters on the *JC* record.

### **Alternative Formats for Stream Flow and Evaporation-Precipitation Datasets**

Monthly stream flow volumes and evaporation-precipitation depths are processed by *HYD* in the following three phases.

1. The monthly stream flow volumes and evaporation-precipitation depths are read from FLO, EVA, DSS, OUT, and/or HYD input files near the beginning of an execution of program *HYD* and stored in the FLOW and EP arrays. The data undergoes certain manipulations during the process of being read and stored in computer memory in the FLOW and EP arrays.
2. The data in the FLOW and EP arrays may be modified by the various *HYD* operations controlled by *JC*, *CP*, *CI*, *AN*, *EP*, *AS*, *RS*, and *EQ* input records from the HIN file.
3. The data in the FLOW and EP arrays are recorded in FLO, EVA, DSS, and/or HOT output files near the end of the program execution.

*HYD* reads input files near the beginning of the data handling and computational tasks and writes to output files near the end. The format for the output files may be different than that of the input files. Using *HYD* to convert flow and evaporation-precipitation data files between formats consists simply of reading input files in any particular format and writing to output files in any selected different format. Input and output options are controlled by the job control variables on the *JC* record.

The format of *IN* and *EV* records in FLO and EVA files or a DSS file are the same for program *HYD* input and output datasets and program *SIM* input datasets. *IN* and *EV* records in FLO and EVA files may be grouped by year or grouped by control point. Each *IN* or *EV* record corresponds to both a year and a control point. The records may be grouped by year, with the group for each year consisting of records for all control points. Alternatively, records may be grouped by control point with records for all of the years grouped together for a control point followed by records for all years for the next control point.

In the standard format, each *IN* and *EV* record has 12 values for the 12 months of the year. Early versions of *WRAP* used a hydrology input file with filename extension HYD containing *IN* and *EV* records in a format with two records per year with six months on each record. Program *HYD* can read data in this *SIM* input HYD file format, store the data in the FLOW and EP arrays, with or without subsequent adjustments, and then write the data in any of the output format options.

Input and output datasets may be converted between text files and binary DSS files. DSS files are the same for either *SIM* or *HYD*. Datasets may also be converted between *IN* and *EV*

records in text file or DSS file formats and columnar formats useful in transporting to Microsoft Excel spreadsheets. *SIM* does not read the columnar format created and/or read by *HYD*.

Flow records read by *HYD* from a FLO file or output by *HYD* to a FLO or HOT file normally begin with the record identifier *IN* as the first two characters. However, the optional parameter CDO entered in *JC* record field 21 replaces the identifier *IN* on the flow records written by *HYD* to the FLO and OUT files with the two-character entry for CDO. The records read by *HYD* from a FLO file may have record identifiers *IN* or CDO. For example, entering *FA* for CDO in *JC* record field 21 allows the *HYD* operations designed for flows on *IN* records to also be applied to flows on *FA* records. Records with the identifier *FA* instead of *IN* can be read and/or created. Thus, spring flows on *FA* records in a *SIM* input FAD file can be created or adjusted.

As discussed in the following Chapter 4, stream flow volumes and evaporation-precipitation depths may be read from a *SIM* OUT file and stored in the FLOW and EP arrays for later output in any of the alternative formats. Stream flow volumes and evaporation-precipitation depths along with other variables read from an OUT file may also be written directly to a HOT file with *OI* records without being stored in the FLOW and EP arrays. The *OI* record is unique in writing a variety of variables directly to the HOT file without going through the FLOW and EP arrays which are subject to various data manipulations.

### Alternative Data Formats

Stream flow volumes and evaporation-precipitation depths are stored in input and output files in the following optional alternative formats.

- *IN* and *EV* records arranged in alternative sequences grouped either by year or by control point and stored in text files typically with extensions FLO and EVA though programs *SIM* and *HYD* also optionally read an input file with extension HYD.
- *IN* and *EV* records in a Hydrologic Engineering Center (HEC) Data Storage System (DSS) file with filename extension DSS.
- Columns in a text file stored in *HYD* input files with filename extensions FLO and EVA or in a *HYD* output file with filename extension HOT.

The format of *IN* and *EV* records is the same in program *SIM* input files and program *HYD* input and output files. *IN* and *EV* records are described in Chapter 3 of the *Users Manual* dealing with *SIM* and in this Chapter 3 of this *Hydrology Manual* dealing with *HYD*. DSS records are described below. The columnar format also described below is applicable only to *HYD*.

### DSS Files

Hydrologic Engineering Center (HEC) Data Storage System (DSS) files are in a direct access binary format that can be read only by software with HEC-DSS capabilities. The WRAP programs are linked at compilation with a HEC-DSS library of routines allowing them to read input data and store simulation results as HEC-DSS files. As outlined in detail in Chapter 6 of the *Users Manual* and discussed throughout the *Users* and *Reference Manuals*, DSS files and *HEC-DSSVue* are fully integrated with the WRAP programs.

DSS files always have the filename extension DSS. Data records are labeled by pathnames that consist of six parts in the format /A/B/C/D/E/F/. DSS pathnames for the data records stored in DSS files of *HYD* input and output time series and *SIM* hydrology input time series data are in the standard format outlined in Table 3.4.

Table 3.4  
Pathnames for *HYD* Input and Output Time Series and *SIM* Hydrology Input DSS Files

- Part A – filename root of input or output file
- Part B – control point identifier
- Part C – IN or EV indicating stream flow *IN* or evaporation-precipitation *EV* records
- Part D – date of the beginning of the time series such as 01JAN1940
- Part E – 1MON for monthly time interval
- Part F – blank (not used)

### Columnar Format

Spreadsheet programs such as Microsoft Excel are useful for plotting, regression analyses, and other manipulations of river flow and evaporation/precipitation data. For example, naturalized flows at multiple control points may be developed by adjusting gaged stream flows at gaging stations with different record lengths and with gaps of missing data. Naturalized flows covering different time periods may be transported from *HYD* to Microsoft Excel to apply regression analyses to fill in missing months and extend coverage to a common simulation period for all control points and then back to *HYD* to convert to standard *IN* record format.

*HYD* will write and read monthly stream flow or evaporation/precipitation data in a text file, with the data sequence for each selected control point being in a single column. Working with monthly time series data in columns, of length 12 months times number of years in hydrologic simulation period, is often more convenient than two dimensional arrays with 12 columns for January-December and a row for each year. With the columnar text file format, each column contains all stream flows (or evaporation/precipitation depths) for a particular control point. For example, 1940-2018 monthly naturalized flows at 125 selected control points may be represented by 125 columns with each containing 948 monthly flows. The columns may have different lengths and gaps with missing data.

*HYD* writes the tables in the following format.

Year	Mon	CP-1	CP-2	CP-3	CP-4	CP-5	CP-6
1991	1	778.1	239.8	827.5	452.6	49.2	1723.0
1991	2	3215.4	319.5	4513.2	299.2	64.6	6293.8
1991	3	2185.4	399.4	3149.5	354.1	53.8	5298.1

The year and month columns are each four-characters wide, and the monthly flow volume or monthly evaporation-precipitation depth columns are 10-characters wide with the data right-justified. In reading the table, the first eight characters (year and month columns) are not read by *HYD* and thus may be blank or contain notes or other information. Lines starting with \*\* or 40 blank characters are skipped over. Thus, \*\* may be used to insert notes.

The control points (columns) in the same order in the table as the *CP* records. However, the columns may be in any order in reading a table. Any number of control points ranging from one to the total number of *CP* records may be included in a table. The control point identifiers in the first row must correspond to the identifiers in field 2 of the *CP* records. Every year of the period-of-analysis (with 12 monthly rows per year) must be included in chronological sequence.

### Input Data Format Options

Program *HYD* will read monthly stream flow volumes and evaporation-precipitation depths in the file and record formats described in Table 3.5. The options for reading the river flow and evaporation-precipitation data are selected by entries for JC(1) and JC(2) in fields 5 and 6 of the *JC* record. For options 1, 2, 3, and 4, the monthly river inflow volumes and evaporation, precipitation, or net evaporation-precipitation depths are read as sets of *IN* and *EV* records. For option 5, these data are read as a table with each column containing the data for a particular control point. With option 6, the data are read from a data storage system DSS file with a fixed pathnames assigned within *HYD*, with no format options to be selected, which can be edited with *HEC-DSSVue*. With option 7, the data are read from a *SIM* simulation output OUT file.

Table 3.5  
Options for *HYD* Stream Flow and Evaporation-Precipitation Input Data Organization

JC(1), JC(2) Option	Filename Extension	Format Description
1	FLO and EVA	Records are grouped by year. Records for all control points for a year are followed by a complete set of records for the next year. Each record contains 12 values for the 12 months of the year.
2	FLO and EVA	Records are grouped by control point. Records for all years for a control point are followed by a complete set of annual records for the next control point. Otherwise, option 2 is the same as option 1.
3	HYD	<i>IN</i> records for all control points for a year are followed by <i>EV</i> records for all control points for the year with pairs of records with each record covering six months. The set of all <i>IN</i> records for one year is followed by the set of <i>EV</i> records for that year.
4	HYD	Same sequencing as option 3 but each record covers 12 months.
5	FLO&EVA	The data are in columns of a table rather than <i>IN</i> and <i>EV</i> records.
6	DSS	Data are read from a DSS file which has a standard binary format.
7	OUT	The data are read from a <i>SIM</i> output OUT file.

Optional hydrology time series input formats for *SIM* are defined by INEV in *JO* record field 2 as described in Chapter 3 of the *Users Manual* [2]. Alternative time series input file formats for *HYD* are specified by input parameter INFILE in *HS* record field 4 (Table 2.1) covered in the preceding Chapter 2 or JC(1) and JC(2) in *JC* record fields 5 and 6. The *HYD JC* record JC(1) and JC(2) options are compared with the *SIM JO* record INEV options as follows.

- JC(1)/JC(2) options 1, 2, and 6 are the same as INEV options 1, 2, and 6.
- JC(1)/JC(2) option 3 is the same as INEV option 5.
- JC(1)/JC(2) option 4 is the same as INEV option 3.
- JC(1)/JC(2) option 2 can be used to replicate INEV option 4.
- JC(1)/JC(2) options 5 and 7 have no *SIM* INEV counterpart.

In the JC(1) and JC(2) option 1 format which is equivalent to INEV option 1 for *SIM*, records for all control points are grouped together for each year. The set of all records for a year is followed by the set of all records for the next year. The option 1 format is designed to allow program *SIM* to store one year of data at a time. Thus, computer memory requirements are greatly reduced for *SIM* relative to storing all the data in memory with option 2. However, compiling data by control point is usually more convenient. Option 2 listed in Table 3.5 allows the records for all years for a particular control point to be grouped together.

The *IN* and *EV* record format and file organization have been restructured in recent versions of *WRAP* compared to its early predecessor *WRAP2/WRAP3* versions. However, *HYD* and *SIM* include options for reading *IN* and *EV* records in either the old or new record and file formats. With the current standard approach, the *IN* and *EV* records are in a 12-months-per-record format and are separated into two files, with filename extensions FLO and EVA. In the old *WRAP2/WRAP3* method (option 3 in the Table 3.5), each record covers six-months (two records per year), and the *IN* and *EV* records are combined and stored as a hydrology root.HYD file. Program *HYD* has an option that reads an old-format file with extension HYD and converts to the new format FLO and EVA files.

*SIM* can also read *IN/EV* records from a DAT file. Option 4 allows the *IN/EV* records in *SIM* DAT file format to be read by program *HYD* from a HYD file and written to FLO and EVA files in the format required for a *SIM* DAT file. The *IN/EV* records can be transferred between a *SIM* DAT file and *HYD* HYD and FLO/EVA files.

Option 5 facilitates transporting data between a spreadsheet program such as Microsoft Excel and *WRAP-HYD*. With the fifth option, the data are read as columns from a spreadsheet table rather than as rows of *IN/EV* records. *HYD* writes stream flow and evaporation-precipitation data in this same format if specified by JC(8) and JC(9) on the *JC* record.

With input option 6 specified by JC(1) or JC(2), a data storage system DSS file with filename root1.DSS is opened and read. With output option 6 specified by JC(8), a DSS file with filename root2.DSS is opened, and the flows and evaporation-precipitation depths are written to the DSS file. The DSS hydrology file follows a standard organizational format common to both *SIM* and *HYD* which is described in Chapters 3 and 6 of the *Users Manual* [2].

With JC(1) and JC(2) input option 7, monthly stream flow volumes and/or evaporation-precipitation depths are read from a *SIM* output OUT file. Variables read by program *HYD* from the *SIM* output OUT file are listed in Table 3.1. JC(1) and JC(2) input option 7 results in the *FLOW*(cp,year,month) and/or *EP*(res,year,month) arrays being initially filled with the data read from the OUT file. Parameters JC(4) and JC(5) are used to select the variable to be adopted.

As previously discussed, data read from the OUT input file are stored in their own arrays which are used by *HYD* for multiple purposes. The data may populate the *FLOW(cp,yr,month)* and/or *EP(res,yr,month)* arrays at the beginning of the *HYD* execution or be used in other ways. The OUT file input data can be used as later adjustments to the *FLOW(cp,yr,month)* array as controlled by *AS* and *AN* records. OUT file input transferred to the *EP(cp,yr,month)* array can be used in *AN* and *EP* record operations. The OUT input file data can also be printed directly to the *HYD* output HOT file in a specified format as controlled by *OI* records. The *OI* record feature is designed to convert *SIM* output to *SIM* or *HYD* input data records.

### Output Data Format Options

*HYD* records monthly stream flow volumes and evaporation-precipitation depths in files organized in the alternative formats listed in Table 3.6. The options for writing the flow and evaporation-precipitation data are selected by entries for JC(8) and JC(9) in fields 12 and 13 of the *JC* record.

Table 3.6  
Options for *HYD* Stream Flow and Evaporation-Precipitation Output Data Organization

JC(8), JC(9) Option	Filename Extension	Format Description
1	FLO and EVA	Records are grouped by year. Records for all control points for a year are followed by a complete set of records for the next year. Each record contains 12 values for the 12 months of the year. Same as JC(1) and JC(2) option 1.
2	FLO and EVA	Records are grouped by control point. Records for all years for a control point are followed by a complete set of records for the next control point. Otherwise, option 2 is the same as option 1. Same as JC(1) and JC(2) option 2.
3	HOT	Records are grouped by year. The set of <i>IN</i> records for a year are followed by the set of <i>EV</i> records for that year.
4	HOT	Records are grouped by control point. The set of all <i>IN</i> records is followed by the set of all <i>EV</i> records.
5	FLO&EVA	The data are written as columns of a table rather than <i>IN</i> and <i>EV</i> records. Same as JC(1) and JC(2) option 5.
6	DSS	Data are written to a DSS file which has a standard binary format. Same as JC(1) and JC(2) option 6.

### Miscellaneous HYD Output Information

The central focus of *HYD* is working with time sequences of monthly stream flow volumes and evaporation-precipitation depths which are stored in input and output files as outlined in the preceding section. Like all the WRAP programs, *HYD* also writes trace messages

and warning and error messages to its message HMS file. *HYD* also creates in its HOT file the optional miscellaneous tabulations listed that may be useful to model users for various purposes.

- JC(10) on the *JC* record creates a table of watershed parameters developed from the data read from a flow distribution DIS file.
- The parameter NEGINC on the *JC* record creates a listing of negative incremental flow adjustments computed as described in *Reference Manual* Chapter 3.
- RS(6) on one or more reservoir specifications *RS* records creates a table showing the component parts of reservoir adjustments. *JC* record JC(11) opens the HOT file if it is not already opened. RS(6) selects individual reservoirs for which to create tables.
- *OI* records allow any variables from a *SIM* output OUT file listed in Table 4.1 of Chapter 4 to be written by *HYD* to the HOT file in the format of *SIM* input records.
- Information written to the HOT file controlled by the parameter FE(1) on the flow extension *FE* record is discussed in Chapter 5.

### **Examples of Creating Datasets with *HYD***

Four simple examples are provided here to illustrate the content and format of the *HYD* input and output. The input data files are available along with the compilation of input files for all of the examples in all of the WRAP manuals. These four examples provide a starting point for model users to create other datasets allowing experimentation with other features of interest. Experimentation with simple easily-trackable examples is typically worthwhile prior to applying the model to large complex real-world datasets.

Examples 3.1, 3.2, and 3.3 demonstrate basic *AS*, *FA*, *RS*, *SC*, *CI* record stream flow adjustment features and also include *EP* record evaporation-precipitation manipulations. Examples 3.1 and 3.2 are identical except for the format of the input and output. Example 3.2 is included to further illustrate input/output format options. *IN* and *EV* records in Examples 3.1 and 3.3 are input in the optional control point grouping format and output in standard format. Example 3.2 uses the columnar table format for the stream flow input file rather than *IN* records. Example 3.4 focuses on distribution of stream flows from gaged to ungaged control points. *IN* records for Example 3.4 are provided alternatively as a standard-format FLO file and an old-format root1.HYD file.

### **Example 3.1 – Naturalized Flow and Net Evaporation-Precipitation Files**

The Example 3.1 river basin configuration is modeled with four control points (labeled CP-1, CP-2, CP-3, CP-4) representing locations in the river system. Two other control points (CP1E and CP2P) serve as identifiers for evaporation (CP1E) and precipitation (CP1P) datasets for reservoir Res located at CP-1. An input file with filename HYDexam31.DAT contains:

- job control *JC* and control point *CP* records
- an *EP* record activating an evaporation-precipitation combining operation
- adjustment specification *AS* records and information for adjusting the flows for a *FA* record series of inflows/outflows and for the effects of a reservoir described by *RS* and *SC* records

Evaporation and precipitation depths (*EV* records) are provided in file HYDexam31.EVA with the control point identifiers CP1E and CP1P. The same sets of 12 monthly evaporation and precipitation depths are repeated for each of the three years of the period-of-analysis. An *EP* record in the DAT file specifies that the precipitation be subtracted from the evaporation, and that the resulting net evaporation-precipitation depths be assigned to control point CP-1. The output file Exam31OUT.EVA contains only the computed *EV* records for CP-1. *EV* records for all other control points are omitted from the output file as specified by parameter INEV on the *CP* records. The net evaporation-precipitation depths are also used in the reservoir evaporation-precipitation computations performed in adjusting stream flows as instructed by the *RS* record.

Observed stream flows (*IN* records) are provided as an inflow file with the filename HYDexam31.FLO. The flows are adjusted as specified by *AS* records using data from *FA* and *RS/SC* records. Each adjustment occurs at a specified control point and all downstream sites. Channel losses are considered in cascading the adjustments through the reach below CP-3. Stream flows at CP-2 and downstream control points CP-3 and CP-4 are adjusted based on inflows/outflows provided on *FA* records for all three years of the period-of-analysis. Flows at CP-1 and downstream control points CP-3 and CP-4 are adjusted for the effects of the reservoir at CP-1 following the specifications from the *RS* record. The default selection of components to include in the reservoir adjustments is adopted. The stream flow adjustments for the effects of the reservoir cover the last two years of the three-year hydrologic period-of-analysis.

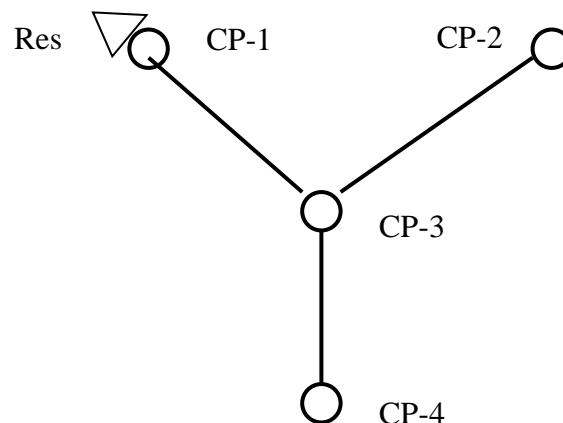


Figure 3.1 Control Point System Schematic for Example 3.1

The configuration of the river basin system is shown in the above schematic. The three input files and four output files are presented on the following pages. The filenames (root.extension) of the input files have a root1 of *HYDexam1* and extensions *DAT*, *FLO*, and *EVA*. The output filenames have a root2 of *HYDexam31OUT* and extensions *HMS*, *HOT*, *FLO* and *EVA*. The automatic *HYD* default convention was adopted in which program *HYD* internally creates root2 by adding *OUT* to root1.

The message file HYDexam31OUT.HMS tracks program progress in reading the input files, performing computations, and developing output files. The *WRAP-HYD* output files HYDexam31OUT.FLO and HYDexam31OUT.EVA contain the final adjusted flows and

evaporation-precipitation depths in formats specified by *JC* records fields 12 and 13 that illustrating two different alternative format options. The EVA output file is in standard *EV* record format designed to serve as an input file for *WRAP-SIM*. The table in the FLO output file is a tabulation of the final adjusted stream flows as specified by *JC* record field 12 in a column format that facilitates transporting the data to a spreadsheet program such as *Microsoft Excel* for plotting or various computational manipulations. The *HYD* output HOT file contains a table, which is activated by an entry in *RS* record field 8 that shows the intermediate results of determining stream flow adjustments for the effects of the reservoir.

Table 3.6  
*HYD* Input HIN File for Example 3.1

```

** WRAP-HYD Input File HYDexam31.HIN
** Example 3.1 from Hydrology Manual
**
**      1      2      3      4      5      6      7      8      9
**3456789012345678901234567890123456789012345678901234567890
**      !      !      !      !      !      !      !      !      !
**
JC 2015   3   1   2   2   1   0   0   0   0   5   1   0   1
**
** CP records for four actual control points (CP-1, CP-2, CP-3, and CP-4) and
** evaporation (CP1E) and precipitation (CP1P) data set identifiers for CP-1.
**
CP CP1E
CP CP1P      4   2   none
CP CP-1   CP-3      none 10000.
CP CP-2   CP-3      2      none
CP CP-3   CP-4      2      none      0.3
CP CP-4   OUT      2   2   CP-3   none
**
** The net evaporation-precipitation for CP-1 is computed by subtracting the
** precipitation assigned to CP1P from the evaporation entered with CP1E.
**
EP CP-1   CP1E      1.0   CP1P      -1.0
**
** FA record adjustments at CP-2 and downstream control points for three years.
**
AS CP-2      1      3
FA 100      100      100      100      100      100      -100      -100      -100      0      0      0
FA 100      100      100      100      100      100      -100      -100      -100      0      0      0
FA 100      100      100      100      100      100      -100      -100      -100      0      0      0
**
** Reservoir Res-A adjustments at CP-1 and downstream control points for two years.
**
AS CP-1      2016      2017   2      3
RS Res      1      2000      0.1      1.0      2000
SC 2000      2000      1500      1000      500      0      1000      2000      3000      2500      2000      1500
SC 2000      2000      1500      1000      500      0      1000      2000      3000      2500      2000      1500
**
ED

```

Table 3.7  
*HYD* FLO Input File for Example 1

```

** WRAP-HYD Input File HYDexam31.FLO
** Example 1 from Hydrology Manual
** Gaged Streamflows in acre-feet
**
IN CP-1      2015      1000      1000      1000      1000      1000      1000      1000      1000      1000      1000      1000      1000
IN CP-1      2016      500      500      500      500      500      500      500      500      500      500      500      500

```

IN	CP-1	2017	0	0	0	0	0	0	0	0	0	0	0	0
IN	CP-2	2015	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
IN	CP-2	2016	500	500	500	500	500	500	500	500	500	500	500	500
IN	CP-2	2017	0	0	0	0	0	0	0	0	0	0	0	0
IN	CP-3	2015	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
IN	CP-3	2016	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
IN	CP-3	2017	0	0	0	0	0	0	0	0	0	0	0	0

**Table 3.7**  
***HYD* EVA Input File for Example 3.1**

```

** WRAP-HYD Input File HYDexam31.EVA
** Example 3.1 from Hydrology Manual
** Evaporation (CP1E) and Precipitation (CP1P) for Control Point CP-1 in feet
**
EV CP1E20152017    1.5    1.5    1.5    0.3    0.3    0.3    0.2    0.2    0.2    1.4    1.4    1.4
EV CP1P20152017    0.5    0.5    0.5    0.8    0.8    0.8    0.1    0.1    0.1    1.4    1.4    1.4

```

**Table 3.8**  
***HYD* Message HMS File for Example 3.1**

WRAP-HYD MESSAGE FILE

```

*** Starting to read file HYDexam1.HIN
*** JC record was read.
*** Starting to read CP records.
*** Finished reading CP records.
*** Reading EP records.
*** Read one EP record.
*** Finished reading file HYDexam1.HIN
*****
Number of CP, SV/SA, OI, EP, AN, AS, EQ records read from HIN file.
    6 control point CP records
    3 control points with streamflows read as input
    2 control points with evap-precip read as input
    1 evaporation-precipitation combining EP records
    2 streamflow adjustment AS records
*****
*** Starting to read IN and/or EV records in JC(1),JC(2)=2 format.
*** Reordering IN records and multiplying by factors on CP records.
*** Finished reading IN records from FLO file in JC(1)=2 format.
*** Starting to read EV records from EVA file in JC(2)=2 format.
*** Reordering EV records and multiplying by factors on CP records.
*** Finished reading IN and/or EV records.
*** Starting EP record operations.
*** Finished EP record operations.
*** Starting to adjust flows as specified by AS and/or EQ records.
*** Finished AS and/or EQ record operations
*** Starting to write IN and/or EV records.
*** Finished writing IN and/or EV records.
*** Starting to write streamflows to FLO file in columnar format.
*** Finished writing flows in columnar format.

***** Normal Completion of Program WRAP-HYD *****

```

Table 3.9  
HYD FLO Output File for Example 3.1

WRAP-HYD Output File HYDexam31OUT.FLO

Year	Mon	CP-1	CP-2	CP-3	CP-4
2015	1	1000.0	1100.0	3100.0	3070.0
2015	2	1000.0	1100.0	3100.0	3070.0
2015	3	1000.0	1100.0	3100.0	3070.0
2015	4	1000.0	1100.0	3100.0	3070.0
2015	5	1000.0	1100.0	3100.0	3070.0
2015	6	1000.0	1100.0	3100.0	3070.0
2015	7	1000.0	900.0	2900.0	2930.0
2015	8	1000.0	900.0	2900.0	2930.0
2015	9	1000.0	900.0	2900.0	2930.0
2015	10	1000.0	1000.0	3000.0	3000.0
2015	11	1000.0	1000.0	3000.0	3000.0
2015	12	1000.0	1000.0	3000.0	3000.0
2016	1	710.0	600.0	2310.0	2217.0
2016	2	710.0	600.0	2310.0	2217.0
2016	3	183.8	600.0	1783.8	1848.6
2016	4	0.0	600.0	1600.0	1720.0
2016	5	0.0	600.0	1600.0	1720.0
2016	6	0.0	600.0	1600.0	1720.0
2016	7	1507.5	400.0	2907.5	2635.2
2016	8	1522.5	400.0	2922.5	2645.8
2016	9	1537.5	400.0	2937.5	2656.2
2016	10	13.8	500.0	1513.8	1659.6
2016	11	11.2	500.0	1511.2	1657.9
2016	12	8.8	500.0	1508.8	1656.1
2017	1	675.0	100.0	775.0	542.5
2017	2	200.0	100.0	300.0	210.0
2017	3	0.0	100.0	100.0	70.0
2017	4	0.0	100.0	100.0	70.0
2017	5	0.0	100.0	100.0	70.0
2017	6	0.0	100.0	100.0	70.0
2017	7	1005.0	0.0	1005.0	703.5
2017	8	1015.0	0.0	1015.0	710.5
2017	9	1025.0	0.0	1025.0	717.5
2017	10	0.0	0.0	0.0	0.0
2017	11	0.0	0.0	0.0	0.0
2017	12	0.0	0.0	0.0	0.0

Table 3.9  
HYD EVA Output File for Example 3.1

WRAP-HYD Output File HYDexam1OUT.EVA

EV	CP-1	2015	1.000	1.000	1.000	-0.500	-0.500	-0.500	0.100	0.100	0.100	0.000	0.000	0.000
EV	CP-1	2016	1.000	1.000	1.000	-0.500	-0.500	-0.500	0.100	0.100	0.100	0.000	0.000	0.000
EV	CP-1	2017	1.000	1.000	1.000	-0.500	-0.500	-0.500	0.100	0.100	0.100	0.000	0.000	0.000

Table 3.10  
HYD Output HOT File for Example 3.1

WRAP-HYD Output File HYDexam1OUT.HOT

Adjustments for the Effects of Reservoir Res  
at Control Point CP-1 with Capacity of 2000.0 acre-feet

Year	Month	RS (1) & RS (2)		RS (3)	RS (4)	RS (5)	Total		
		Ending	Mean	Runoff	Storage	Precip		Site	
		Storage	Area	Depth	Change	Spill		-Evap	Runoff
Adjustment		(ac-ft)	(acres)	(feet)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	
2016	1	2000.0	200.0	0.050	0.0	0.0	200.0	10.0	210.0
2016	2	2000.0	200.0	0.050	0.0	0.0	200.0	10.0	210.0
2016	3	1500.0	175.0	0.050	-500.0	0.0	175.0	8.8	-316.3
2016	4	1000.0	125.0	0.050	-500.0	0.0	-62.5	6.3	-556.3
2016	5	500.0	75.0	0.050	-500.0	0.0	-37.5	3.8	-533.8
2016	6	0.0	25.0	0.050	-500.0	0.0	-12.5	1.3	-511.3
2016	7	1000.0	50.0	0.050	1000.0	0.0	5.0	2.5	1007.5
2016	8	2000.0	150.0	0.050	1000.0	0.0	15.0	7.5	1022.5
2016	9	3000.0	250.0	0.050	1000.0	0.0	25.0	12.5	1037.5
2016	10	2500.0	275.0	0.050	0.0	500.0	0.0	13.8	-486.3
2016	11	2000.0	225.0	0.050	0.0	500.0	0.0	11.3	-488.8
2016	12	1500.0	175.0	0.050	-500.0	0.0	0.0	8.8	-491.3
2017	1	2000.0	175.0	0.000	500.0	0.0	175.0	0.0	675.0
2017	2	2000.0	200.0	0.000	0.0	0.0	200.0	0.0	200.0
2017	3	1500.0	175.0	0.000	-500.0	0.0	175.0	0.0	-325.0
2017	4	1000.0	125.0	0.000	-500.0	0.0	-62.5	0.0	-562.5
2017	5	500.0	75.0	0.000	-500.0	0.0	-37.5	0.0	-537.5
2017	6	0.0	25.0	0.000	-500.0	0.0	-12.5	0.0	-512.5
2017	7	1000.0	50.0	0.000	1000.0	0.0	5.0	0.0	1005.0
2017	8	2000.0	150.0	0.000	1000.0	0.0	15.0	0.0	1015.0
2017	9	3000.0	250.0	0.000	1000.0	0.0	25.0	0.0	1025.0
2017	10	2500.0	275.0	0.000	0.0	500.0	0.0	0.0	-500.0
2017	11	2000.0	225.0	0.000	0.0	500.0	0.0	0.0	-500.0
2017	12	1500.0	175.0	0.000	-500.0	0.0	0.0	0.0	-500.0
Adjustment Means					62.5	83.3	41.2	4.0	24.4

### **Example 3.2 – Naturalized Flow and Net Evaporation-Precipitation Files**

Example 3.2 consists of repeating Example 3.1 using different input data options. The sole purpose of Example 3.2 is to further illustrate variations in input options. Numeric data for the majority of the input records in the files HYDexam32.HIN and HYDexam32.EVA are entered in comma-delimited format rather than the standard fixed-width-field format adopted in Example 31. Fixed-width format is recommended since it is easier for people to read, but the comma-delimited format is also an option. The stream flows are entered in file HYDexam32.FLO as columns of a table rather than as *IN* records. The output files HYDexam32OUT.FLO and HYDexam32OUT.EVA are in standard *IN* and *EV* record format.

Table 3.10  
*HYD* Input HIN File for Example 3.2

```
** WRAP-HYD Input File HYDexam32.HIN
** Example 3.2 from Hydrology Manual
** Examples 3.1 and 3.2 are identical except for format options.
**
JC 2015,3,1,5,2,1,0,0,0,0,1,1,
**
** CP records for four actual control points (CP-1, CP-2, CP-3, and CP-4) and
** evaporation (CP1E) and precipitation (CP1P) data set identifiers for CP-1.
**
CP CP1E                2      none
CP CP1P                4      2      none
CP CP-1      CP-3                none 10000.
CP CP-2      CP-3                2      none
CP CP-3      CP-4                2      none 0.3
CP CP-4      OUT                2      2      CP-3      none
**
** The net evaporation-precipitation for CP-1 is computed by subtracting the
** precipitation assigned to CP1P from the evaporation entered with CP1E.
**
EP CP-1      CP1E      1.0      CP1P      -1.0
**
** FA record adjustments at CP-2 and downstream control points for three years.
**
AS CP-2,,1,,,,,3
FA 100,100,100,100,100,100,-100,-100,-100,,,,
FA 100,100,100,100,100,100,-100,-100,-100,,,,
FA 100,100,100,100,100,100,-100,-100,-100,,,,
**
** Reservoir Res-A adjustments at CP-1 and downstream control points for two years.
**
AS CP-1 2015,2017,-2,,,,,3,
RS Res ,,,,,,2000,0.1,1.0,0.0,2000,
SC CP-1 2016,2000,2000,1500,1000,500,0,1000,2000,3000,2500,2000,1500,
SC CP-1 2017,2000,2000,1500,1000,500,0,1000,2000,3000,2500,2000,1500,
**
ED
```

Table 3.11  
*HYD* EVA Input File for Example 3.2

```
** WRAP-HYD Input File HYDexam32.EVA
** Example 3.2 from Hydrology Manual
** Evaporation (CP1E) and Precipitation (CP1P) for Control Point CP-1 in feet
EV CP1E20152017 1.5,1.5,1.5,0.3,0.3,0.3,0.2,0.2,1.4,1.4,1.4,
EV CP1P20152017 0.5,0.5,0.5,0.8,0.8,0.8,0.1,0.1,0.1,1.4,1.4,1.4,
```

Table 3.12  
*HYD FLO Input File for Example 3.2*

```

** WRAP-HYD Input File HYDexam32.FLO
** Example 3.2 from Hydrology Manual
** Streamflows in Columnar Format
**

```

Year	Mon	CP-1	CP-2	CP-3
2015	1	1000.0	1000.0	3000.0
2015	2	1000.0	1000.0	3000.0
2015	3	1000.0	1000.0	3000.0
2015	4	1000.0	1000.0	3000.0
2015	5	1000.0	1000.0	3000.0
2015	6	1000.0	1000.0	3000.0
2015	7	1000.0	1000.0	3000.0
2015	8	1000.0	1000.0	3000.0
2015	9	1000.0	1000.0	3000.0
2015	10	1000.0	1000.0	3000.0
2015	11	1000.0	1000.0	3000.0
2015	12	1000.0	1000.0	3000.0
2016	1	500.0	500.0	2000.0
2016	2	500.0	500.0	2000.0
2016	3	500.0	500.0	2000.0
2016	4	500.0	500.0	2000.0
2016	5	500.0	500.0	2000.0
2016	6	500.0	500.0	2000.0
2016	7	500.0	500.0	2000.0
2016	8	500.0	500.0	2000.0
2016	9	500.0	500.0	2000.0
2016	10	500.0	500.0	2000.0
2016	11	500.0	500.0	2000.0
2016	12	500.0	500.0	2000.0
2017	1	0.0	0.0	0.0
2017	2	0.0	0.0	0.0
2017	3	0.0	0.0	0.0
2017	4	0.0	0.0	0.0
2017	5	0.0	0.0	0.0
2017	6	0.0	0.0	0.0
2017	7	0.0	0.0	0.0
2017	8	0.0	0.0	0.0
2017	9	0.0	0.0	0.0
2017	10	0.0	0.0	0.0
2017	11	0.0	0.0	0.0
2017	12	0.0	0.0	0.0

Table 3.12  
*HYD* EVA Output File for Example 3.

WRAP-HYD Output File HYDexam2OUT.EVA

EV	CP-1	2015	1.000	1.000	1.000	-0.500	-0.500	-0.500	0.100	0.100	0.100	0.000	0.000	0.000
EV	CP-1	2016	1.000	1.000	1.000	-0.500	-0.500	-0.500	0.100	0.100	0.100	0.000	0.000	0.000
EV	CP-1	2017	1.000	1.000	1.000	-0.500	-0.500	-0.500	0.100	0.100	0.100	0.000	0.000	0.000

Table 3.13  
*HYD* FLO Output File for Example 3.2

WRAP-HYD Output File HYDexam2OUT.FLO

IN	CP-1	2015	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
IN	CP-2	2015	1100.0	1100.0	1100.0	1100.0	1100.0	1100.0	900.0	900.0	900.0	1000.0	1000.0	1000.0
IN	CP-3	2015	3100.0	3100.0	3100.0	3100.0	3100.0	3100.0	2900.0	2900.0	2900.0	3000.0	3000.0	3000.0
IN	CP-4	2015	3070.0	3070.0	3070.0	3070.0	3070.0	3070.0	2930.0	2930.0	2930.0	3000.0	3000.0	3000.0
IN	CP-1	2016	710.0	710.0	183.8	0.0	0.0	0.0	1507.5	1522.5	1537.5	13.8	11.2	8.8
IN	CP-2	2016	600.0	600.0	600.0	600.0	600.0	600.0	400.0	400.0	400.0	500.0	500.0	500.0
IN	CP-3	2016	2310.0	2310.0	1783.8	1600.0	1600.0	1600.0	2907.5	2922.5	2937.5	1513.8	1511.2	1508.8
IN	CP-4	2016	2217.0	2217.0	1848.6	1720.0	1720.0	1720.0	2635.2	2645.8	2656.2	1659.6	1657.9	1656.1
IN	CP-1	2017	675.0	200.0	0.0	0.0	0.0	0.0	1005.0	1015.0	1025.0	0.0	0.0	0.0
IN	CP-2	2017	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
IN	CP-3	2017	775.0	300.0	100.0	100.0	100.0	100.0	1005.0	1015.0	1025.0	0.0	0.0	0.0
IN	CP-4	2017	542.5	210.0	70.0	70.0	70.0	70.0	703.5	710.5	717.5	0.0	0.0	0.0

Table 3.14  
*HYD* Message HMS File for Example 3.2

```

WRAP-HYD MESSAGE FILE

*** Starting to read file HYDexam32.HIN
*** JC record was read.
*** Starting to read CP records.
*** Finished reading CP records.
*** Reading EP records.
*** Read one EP record.
*** Finished reading file HYDexam32.HIN
*****
Number of CP, SV/SA, OI, EP, AN, AS, EQ records read from HIN file.
    6 control point CP records
    3 control points with streamflows read as input
    2 control points with evap-precip read as input
    1 evaporation-precipitation combining EP records
    2 streamflow adjustment AS records
*****
*** Starting to read IN and/or EV records in JC(1),JC(2)=2 format.
*** Starting to read EV records from EVA file in JC(2)=2 format.
*** Reordering EV records and multiplying by factors on CP records.
*** Finished reading IN and/or EV records.
*** Starting to read flows and/or evap-precip in columnar format.
*** Starting to read streamflows from FLO file in columnar format.
*** Finished reading flows and/or evap-precip.
*** Starting EP record operations.
*** Finished EP record operations.
*** Starting to adjust flows as specified by AS and/or EQ records.
*** Finished AS and/or EQ record operations
*** Starting to write IN and/or EV records.
*** Finished writing IN and/or EV records.

***** Normal Completion of Program WRAP-HYD *****

```

### **Example 3.3 – Naturalized Flow and Net Evaporation-Precipitation Files**

The river basin configuration is represented by four control points labeled CP-1, CP-2, CP-3, and CP-4 that are located in series on the same stream. A reservoir with identifier RES-A is located at control point CP-2. A file with filename HYDexam33.HIN contains:

- job control *JC* and control point *CP* records
- *EP* records activating evaporation-precipitation combining operations
- specifications and information for adjusting the flows for a constant annual set of inflows/outflows (*CI* records), multiple-year series of inflows/outflows (*AS* and *FA* records), and the effects of reservoir RES-A (*AS*, *RS*, *SC*, and *SV/SA* records)

Observed stream flows (*IN* records) are provided in an inflow file with the filename HYDexam33.FLO. Evaporation and precipitation rates (*EV* records) for the reservoir adjustments are provided in the file HYDexam33.EVA. *WRAP-HYD* performs the evaporation-precipitation manipulations and stream flow adjustments and writes the resulting net evaporation-precipitation (*EV* records) and naturalized stream flows (*IN* records) to output files with filenames HYDexam33OUT.EVA and HYDexam33OUT.FLO. The three input files (root1 of HYDexam33 and extensions DAT, FLO, and EVA) and two output files (root2 of HYDexam33OUT and extensions FLO and EVA) are presented on the following pages.

Net evaporation-precipitation rates (*EV* records) for control points CP-1 and CP-2 are provided in file HYDexam33.EVA. An *EP* record in the HIN file specifies that the CP-2 net evaporation-precipitation depths be computed by averaging the depths at CP-1 and CP-3. The output file HYDexam33OUT.EVA contains only the *EV* records for CP-1, CP-2, and CP-3.

The stream flows entered in the file HYDexam33.FLO are adjusted as specified by *AS* records using data from *CI*, *FA*, and *RS/SC/SV/SA* records. All of the *RS* record defaults are adopted for the component adjustments for the effects of the reservoir at CP-2. Each adjustment occurs at a specified control point and all downstream locations. After accumulating all adjustments, any negative stream flows are set to zero with a final *AS* record with negative flow option 2 specified in field 9 and a constant adjustment of zero specified in fields 5 and 11.

Table 3.15  
*HYD* Input HIN File for Example 3.3

```

T1 WRAP-HYD Input File HYDexam33.DAT
T2 Example 3.3 from Hydrology Manual
**
**      1      2      3      4      5      6      7      8      9
**3456789012345678901234567890123456789012345678901234567890
**      !      !      !      !      !      !      !      !      !
JC 2016      3      2      2      2      1      !      !      !      !      !      !      !      !
**
CP CP-1      CP-2
CP CP-2      CP-3      0      NONE      10000
CP CP-3      CP-4
CP CP-4      2      NONE
**

```

```

CI  CP-3      20      20      20      20      20      20
CI      -10     -20    -100      50      50      50
**
SV RES-A      0     100     200     400     600     800    1000
SA      0       20      40      80     120     160     200
**
** The net evaporation-precipitation EV records for CP-2 are developed by averaging the
** net evaporation-precipitation depths from EV records for CP-1 and CP-3.
**
EP  CP-2      CP-1      1.0      CP-3      1.0
**
** CI record adjustments at CP-3 and downstream control points repeated for each of three
** years.
**
AS  CP-3      2016      2018      3
**
** FA record adjustments at CP-3 and downstream control points for three years.
**
AS  CP-3      1
FA  100      100      100     -100     -100     -100      0      0      0      50      50      50
FA  -40      -30      -30      0       20      20      50      50      50      50      80      80
FA   25       0       5       18      12     -18      15      26      19      15      12      20
**
** Reservoir Res-A adjustments at CP-2 and downstream control points for two years.
**
AS  CP-2      2017      2018      2
RS RES-A      800
SC  800      800      800      700      500      500      600      700      800      900      850      800
SC  800      800      800      750      750      750      760      770      780      790      800      800
**
** FA record adjustments at CP-1 and downstream control points for one year.
**
AS  CP-1      2017      2017      1
FA  10       10       10      20      20      20      0      0      0     -10     -30     -20
**
** Any negative flows are set to zero with the negative amount subtracted the next-month.
**
AS  CP-1      2016      2018      0      0      0      0      4
**
ED

```

**Table 3.16**  
**HYD EVA Input File for Example 3.3**

```

** WRAP-HYD Input File HYDexam33.EVA
** Example 3.3 from Hydrology Manual
**
EV CP-1      2016      0.21     -0.12     0.15     -0.12     0.43     0.55     0.17     0.49     0.51     0.42     -0.08     0.13
EV CP-1      2017      0.17     0.21     0.39     0.35     0.48     0.51     0.42     0.22     0.38     0.23     0.12     0.21
EV CP-1      2018      0.34     0.12     0.36     0.38     0.42     0.32     0.24     0.18     0.52     0.46     0.39     0.38
**
EV CP-3      2016      0.10     0.00     0.08     -0.10     0.52     0.41     0.02     0.01     0.25     0.09     0.06     -0.05
EV CP-3      2017      0.00     0.06     0.23     0.24     0.42     0.56     0.44     0.30     0.12     0.22     0.12     0.01
EV CP-3      2018      0.12     -0.18     0.15     0.22     0.45     0.18     0.11     0.03     0.36     0.15     0.33     0.26

```

**Table 3.17**  
**HYD FLO Input File for Example 3.3**

```

** WRAP-HYD Input File HYDexam33.FLO
** Example 3.3 from Hydrology Manual
**
IN CP-1 2016 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000
IN CP-1 2017 3600 400 20 160 140 50 0 210 1400 2200 3100 3200
IN CP-1 2018 6500 6500 6500 6500 6500 6500 7500 7500 7500 7500 7500
**
IN CP-2 2016 5000 5000 5000 5000 5000 5000 5000 5000 5000 5000 5000 5000
IN CP-2 2017 4200 600 50 250 320 80 10 390 2300 3100 4800 4400
IN CP-2 2018 7100 8200 7000 7200 6900 5500 6700 6500 7300 8100 7900 8300
**
IN CP-3 2016 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000
IN CP-3 2017 5500 650 520 560 520 440 90 520 3500 4200 6500 7500
IN CP-3 2018 7600 9600 8200 8200 7300 7300 7300 7300 8600 8600 8600 8600
**
IN CP-4 2016 8000 8000 8000 8000 8000 8000 8000 8000 8000 8000 8000 8000
IN CP-4 2017 7200 1200 1400 2200 1600 1200 850 1400 5200 5700 7200 9200
IN CP-4 2018 9300 12500 8500 9700 8200 7900 7600 8300 9700 9100 8900 10500

```

**Table 3.18**  
**HYD FLO Output File for Example 3.3**

```

WRAP-HYD Output File HYDexam3OUT.FLO

IN CP-1 2016 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0
IN CP-1 2017 3610.0 410.0 30.0 180.0 160.0 70.0 0.0 210.0 1400.0 2190.0 3070.0 3180.0
IN CP-1 2018 6500.0 6500.0 6500.0 6500.0 6500.0 6500.0 7500.0 7500.0 7500.0 7500.0 7500.0 7500.0
IN CP-2 2016 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0
IN CP-2 2017 4304.4 662.8 160.0 262.2 251.8 207.8 204.7 562.7 2509.5 3319.2 4846.0 4438.9
IN CP-2 2018 7287.2 8321.6 7193.6 7354.6 7134.0 5657.5 6864.0 6641.6 7559.5 8332.9 8150.1 8535.2
IN CP-3 2016 6120.0 6120.0 6120.0 5920.0 5920.0 5920.0 5990.0 5980.0 5900.0 6100.0 6100.0 6100.0
IN CP-3 2017 5584.4 702.8 620.0 592.2 491.8 607.8 324.7 722.7 3659.5 4519.2 6676.0 7668.9
IN CP-3 2018 7832.2 9741.6 8418.6 8392.6 7566.0 7459.5 7469.0 7447.6 8778.5 8897.9 8912.1 8905.2
IN CP-4 2016 8120.0 8120.0 8120.0 7920.0 7920.0 7920.0 7990.0 7980.0 7900.0 8100.0 8100.0 8100.0
IN CP-4 2017 7284.4 1252.8 1500.0 2232.2 1571.8 1367.8 1084.7 1602.7 5359.5 6019.2 7376.0 9368.9
IN CP-4 2018 9532.2 12641.6 8718.6 9892.6 8466.0 8059.5 7769.0 8447.6 9878.5 9397.9 9212.1 10805.2

```

**Table 3.18**  
**HYD EVA Output File for Example 3.3**

```

WRAP-HYD Output File HYDexam33OUT.EVA

EV CP-1 2016 0.210 -0.120 0.150 -0.120 0.430 0.550 0.170 0.490 0.510 0.420 -0.080 0.130
EV CP-1 2017 0.170 0.210 0.390 0.350 0.480 0.510 0.420 0.220 0.380 0.230 0.120 0.210
EV CP-1 2018 0.340 0.120 0.360 0.380 0.420 0.320 0.240 0.180 0.520 0.460 0.390 0.380
EV CP-2 2016 0.310 -0.120 0.230 -0.220 0.950 0.960 0.190 0.500 0.760 0.510 -0.020 0.080
EV CP-2 2017 0.170 0.270 0.620 0.590 0.900 1.070 0.860 0.520 0.500 0.450 0.240 0.220
EV CP-2 2018 0.460 -0.060 0.510 0.600 0.870 0.500 0.350 0.210 0.880 0.610 0.720 0.640
EV CP-3 2016 0.100 0.000 0.080 -0.100 0.520 0.410 0.020 0.010 0.250 0.090 0.060 -0.050
EV CP-3 2017 0.000 0.060 0.230 0.240 0.420 0.560 0.440 0.300 0.120 0.220 0.120 0.010
EV CP-3 2018 0.120 -0.180 0.150 0.220 0.450 0.180 0.110 0.030 0.360 0.150 0.330 0.260

```

### Example 3.4 – Flow Distribution

The flow distribution methods described in Chapter 3 of the Reference Manual are included in both *HYD* and *SIM*. *HYD* is applied in this example synthesize flows at ungaged sites based on flows at gaged sites. Naturalized flows at gaged control points J, K, L, M, and N, stored in *HYD* input file HYDexam4.FLO, are used to compute naturalized flows at ungaged control points I, II, III, and IV. The *HYD* input data are provided in files HYDexam34.HIN, HYDexam34.FLO, and HYDexam34.DIS. The output file created by *WRAP-HYD* includes *IN* records for all nine control points. The stream flow input file is shown alternatively as an FLO file in standard format and as a file with filename HYDexam4.HYD in the optional six flows per record format that also contains evaporation-precipitation depths.

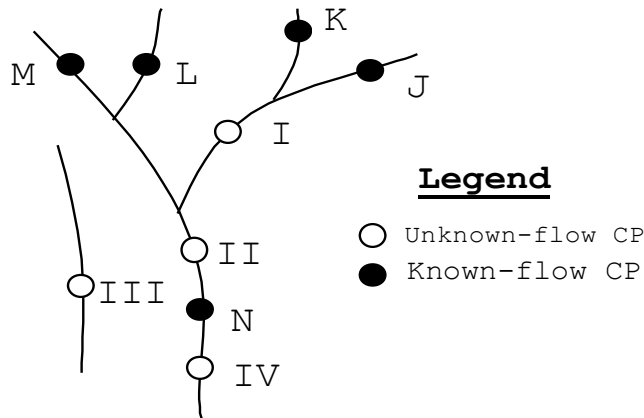


Figure 3.2 System Schematic for Example 3.4

Table 3.19  
HYD Input HIN File for Example 3.4

```
** WRAP-HYD Input File HYDexam4.HIN
** Example 3.4 from Hydrology Manual
**
**      1      2      3      4      5      6      7
**345678901234567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !
** JC record corresponding to use of the input file HYDexam4.FLO.
**JC 2016    2    1    1    0                1    1    0    3
** Alternative JC record for the alternative input file HYDexam4.HYD.
JC 2016    2    1    3    3                1    1    1    3
CP CP-J      CP-I      0      0      0
CP CP-K      CP-I      0      0      0
CP CP-L      CP-II     0      0    2    0      NONE
CP CP-M      CP-II     0      0      0
CP CP-N      CP-IV     0      0      0      0.40
CP CP-I      CP-II     0      0    2    4      NONE
CP CP-II     CP-N      0      0    2    8      NONE      0.25
CPCP-III     OUT      0      0    2    3      NONE
CP CP-IV     OUT      0      0    2    4      NONE
**      !      !      !      !      !      !      !
ED
```

Table 3.20  
*HYD FLO Input File for Example 3.4*

```

** WRAP-HYD Input File HYDexam4.FLO
** Example 3.4 from Hydrology Manual
**
IN CP-J 2016 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000
IN CP-K 2016 5000 5000 5000 5000 5000 5000 5200 5200 5200 5200 5200 5200
IN CP-L 2016 6500 6500 6500 6500 6500 6500 7500 7500 7500 7500 7500 7500
IN CP-M 2016 6000 6000 6000 6000 6000 6000 8000 8000 8000 8000 8000 8000
IN CP-N 2016 50000 50000 50000 50000 50000 50000 50000 50000 50000 50000 50000 50000
**
IN CP-J 2017 4000 400 40 0 80 500 1000 2000 3000 4000 5000 6000
IN CP-K 2017 5000 500 50 0 90 1000 5200 5200 5200 5200 5200 5200
IN CP-L 2017 6500 650 500 0 500 500 7500 7500 7500 7500 7500 7500
IN CP-M 2017 6000 600 60 0 100 900 8000 8000 8000 8000 8000 8000
IN CP-N 2017 50000 5000 500 0 500 100 100000 0 0 100 8000 50000

```

Table 3.21  
*HYD Input File for Example 3.4*  
(File HYDexam34.HYD may be used as an alternative to FLO and/or EVA files.)

```

** WRAP-HYD Input File HYDexam4.HYD
** Example 3.4 from Hydrology Manual
** Inflow IN and evaporation EV records in
** the optional HYD file format.
**
IN CP-J 2016 4000 4000 4000 4000 4000 4000
IN 4000 4000 4000 4000 4000 4000
IN CP-K 2016 5000 5000 5000 5000 5000 5000
IN 5200 5200 5200 5200 5200 5200
IN CP-L 2016 6500 6500 6500 6500 6500 6500
IN 7500 7500 7500 7500 7500 7500
IN CP-M 2016 6000 6000 6000 6000 6000 6000
IN 8000 8000 8000 8000 8000 8000
IN CP-N 2016 50000 50000 50000 50000 50000 50000
IN 50000 50000 50000 50000 50000 50000
EV CP-J 2016 0.5 0.5 0.5 0.5 0.5 0.5
EV 0.5 0.5 0.5 0.5 0.5 0.5
EV CP-K 2016 0.1 0.1 0.1 0.1 0.1 0.1
EV 0.25 0.25 0.25 0.25 0.25 0.25
EV CP-M 2016 0.40 0.40 0.40 0.40 0.40 0.40
EV 0.68 0.68 0.68 0.68 0.68 0.68
EV CP-N 2016 0.21 0.21 0.21 0.21 0.21 0.21
EV 0.333 0.333 0.333 0.333 0.333 0.333
IN CP-J 2017 4000 400 40 0 80 500
IN 1000 2000 3000 4000 5000 6000
IN CP-K 2017 5000 500 50 0 90 1000
IN 5200 5200 5200 5200 5200 5200
IN CP-L 2017 6500 650 500 0 500 500
IN 7500 7500 7500 7500 7500 7500
IN CP-M 2017 6000 600 60 0 100 900
IN 8000 8000 8000 8000 8000 8000
IN CP-N 2017 50000 5000 500 0 500 100
IN 100000 0 0 100 8000 50000
EV CP-J 2017 0.5 0.5 0.5 0.5 0.5 0.5
EV 0.5 0.5 0.5 0.5 0.5 0.5
EV CP-K 2017 0.1 0.1 0.1 0.1 0.1 0.1
EV 0.25 0.25 0.25 0.25 0.25 0.25
EV CP-M 2017 0.40 0.40 0.40 0.40 0.40 0.40
EV 0.68 0.68 0.68 0.68 0.68 0.68
EV CP-N 2017 0.21 0.21 0.21 0.21 0.21 0.21
EV 0.333 0.333 0.333 0.333 0.333 0.333

```

Table 3.22  
*HYD* DIS Input File for Example 3.4

```

** WRAP-HYD Input File HYDexam34.DIS
** Example 3.4 from Hydrology Manual
**
** Flow distribution FD records
**
FD  CP-I      CP-N      2      CP-J      CP-K      CP-L      CP-M
FD CP-II      CP-N      4      CP-J      CP-K      CP-L      CP-M
FDCP-III      CP-N      0      CP-J      CP-K      CP-L      CP-M
FC 0.509
FD CP-IV      CP-N      -1
**
** Watershed parameter WP records
**
WP  CP-J      60.      80      30.
WP  CP-K      75.      76      30.
WP  CP-L      100.     78      31.
WP  CP-M      90.      75      31.
WP  CP-N      600.     79      31.
WP  CP-I      225.     77      31.
WP CP-II      500.     78      31.
WPCP-III      140.     72      32.
WP CP-IV      800      78      31
ED

```

Table 3.23  
*HYD* Output HOT File for Example 3.4

WRAP-HYD Output File HYDexam4out.OUT

Incremental Watershed Parameters for Ungaged (I) and Gaged (J) Control Points

I	J	CP(I)	CP(J)	NG(I)	NG(J)	INMETH	EWA(I)	DA(I)	DA(J)	CN(I)	CN(J)	MP(I)	MP(J)
6	5	CP-I	CP-N	2	4	4	0.0	90.0	275.0	75.83	81.27	32.50	31.49
7	5	CP-II	CP-N	4	4	8	0.0	175.0	275.0	79.71	81.27	31.77	31.49
8	5	CP-III	CP-N	0	4	3	0.0	140.0	275.0	0.00	0.00	0.00	0.00
9	5	CP-IV	CP-N	-1	0	4	0.0	200.0	600.0	75.00	79.00	31.00	31.00

Watershed Parameters from WP Records

CP	CPID	DA	CN	MP
1	CP-J	60.0	80.00	30.00
2	CP-K	75.0	76.00	30.00
3	CP-L	100.0	78.00	31.00
4	CP-M	90.0	75.00	31.00
5	CP-N	600.0	79.00	31.00
6	CP-I	225.0	77.00	31.00
7	CP-II	500.0	78.00	31.00
8	CP-III	140.0	72.00	32.00
9	CP-IV	800.0	78.00	31.00

Table 3.24  
*HYD FLO Output File for Example 3.4*

WRAP-HYD Output File HYDexam4OUT.FLO

IN	CP-J	2016	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0
IN	CP-K	2016	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5200.0	5200.0	5200.0	5200.0	5200.0	5200.0
IN	CP-L	2016	6500.0	6500.0	6500.0	6500.0	6500.0	6500.0	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0
IN	CP-M	2016	6000.0	6000.0	6000.0	6000.0	6000.0	6000.0	8000.0	8000.0	8000.0	8000.0	8000.0	8000.0
IN	CP-N	2016	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0
IN	CP-I	2016	18513.9	18513.9	18513.9	18513.9	18513.9	18513.9	17970.6	17970.6	17970.6	17970.6	17970.6	17970.6
IN	CP-II	2016	45901.7	45901.7	45901.7	45901.7	45901.7	45901.7	47317.4	47317.4	47317.4	47317.4	47317.4	47317.4
INCP-III		2016	17242.4	17242.4	17242.4	17242.4	17242.4	17242.4	16020.8	16020.8	16020.8	16020.8	16020.8	16020.8
IN	CP-IV	2016	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1
IN	CP-J	2017	4000.0	400.0	40.0	0.0	80.0	500.0	1000.0	2000.0	3000.0	4000.0	5000.0	6000.0
IN	CP-K	2017	5000.0	500.0	50.0	0.0	90.0	1000.0	5200.0	5200.0	5200.0	5200.0	5200.0	5200.0
IN	CP-L	2017	6500.0	650.0	500.0	0.0	500.0	500.0	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0
IN	CP-M	2017	6000.0	600.0	60.0	0.0	100.0	900.0	8000.0	8000.0	8000.0	8000.0	8000.0	8000.0
IN	CP-N	2017	50000.0	5000.0	500.0	0.0	500.0	100.0100000.0	0.0	0.0	100.0	8000.0	50000.0	
IN	CP-I	2017	18513.9	1536.5	90.0	0.0	170.0	100.0	31671.0	0.0	0.0	100.0	8000.0	19508.1
IN	CP-II	2017	45901.7	4319.0	650.0	0.0	711.4	1329.7	83526.7	9816.2	10248.6	10756.8	17167.6	48203.6
INCP-III		2017	17242.4	1724.2	6.4	0.0	0.0	0.0	42616.0	0.0	0.0	0.0	0.0	15257.3
IN	CP-IV	2017	43852.1	3953.2	318.4	0.0	318.4	60.0	89383.7	0.0	0.0	60.0	6506.8	43852.1

Table 3.25  
*HYD EVA Output File for Example 3.4*  
(This EVA file is created with the HYDexam34.HYD Input File  
and associated version of the JC record.)

WRAP-HYD Output File HYDexam4OUT.EVA

EV	CP-J	2016	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
EV	CP-K	2016	0.100	0.100	0.100	0.100	0.100	0.100	0.250	0.250	0.250	0.250	0.250	0.250
EV	CP-M	2016	0.400	0.400	0.400	0.400	0.400	0.400	0.680	0.680	0.680	0.680	0.680	0.680
EV	CP-N	2016	0.210	0.210	0.210	0.210	0.210	0.210	0.333	0.333	0.333	0.333	0.333	0.333
EV	CP-J	2017	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
EV	CP-K	2017	0.100	0.100	0.100	0.100	0.100	0.100	0.250	0.250	0.250	0.250	0.250	0.250
EV	CP-M	2017	0.400	0.400	0.400	0.400	0.400	0.400	0.680	0.680	0.680	0.680	0.680	0.680
EV	CP-N	2017	0.210	0.210	0.210	0.210	0.210	0.210	0.333	0.333	0.333	0.333	0.333	0.333

## CHAPTER 4

### SIM INPUT DATASETS BASED ON SIMULATION RESULTS

Chapter 4 describes *HYD* capabilities for incorporating monthly *SIM* or monthly *SIMD* simulation results into *SIM* input datasets. Chapter 4 focuses largely on applying *HYD* capabilities for using *SIM* simulation results to create datasets of stream flows representing specified scenarios of water development and use. Two very different applications that motivated development of these *HYD* features are (1) extending naturalized flows and (2) developing condensed *SIM* input datasets that focus on particular water management systems. These methodologies for extending hydrology and condensing datasets documented here in Chapter 4 were originally proposed and investigated in a case study of the Brazos River Basin water availability model [11].

These generic *HYD* features may be employed for various types of applications. For example, a modeling strategy consists of incorporating environmental instream flow targets computed in a daily *SIMD* simulation into the input dataset for a monthly *SIM* simulation [12]. Instream flow targets computed by *SIMD* using a daily computational time step are aggregated to monthly totals within *SIMD* and recorded in the *SIMD* DSS and/or OUT output files. The *SIMD* output records in the DSS output file are then changed to target series *TS* records in *SIM* DSS input format using the *HEC-DSS* editor. Alternatively, *HYD* can read the monthly summations of instream flow targets from the OUT file and record them as target series *TS* records in the proper format in its output HOT file. The *HYD* output HOT file containing the *TS* records is converted to a *SIM* input TSF file by simply changing the filename extension. *HYD* can read various simulation results from a *SIM* or *SIMD* monthly output OUT file or DSS file, perform arithmetic operations on the data, and record the resulting data series in specified formats in a HOT or DSS file.

Certain tasks can be performed alternatively with either *HYD* or *HEC-DSSVue*, as illustrated by the example noted in the preceding paragraph. Applications may also involve employing *HYD* and *HEC-DSSVue* in combination.

#### **SIM Simulation Results**

*HYD* includes options for reading the variables listed in Table 4.1 from a *SIM* output OUT file. *SIMD* and *SIM* output OUT files are identical in format and treated the same by *HYD*. If an OUT file is read, all of the control point, water right, and reservoir records contained in the OUT file are read. However, only the variables listed in Table 4.1 are read from these records. *HYD* stores the data read from the OUT file (filename root1.OUT) in the following arrays.

*OUTCP* (control point, variable, year, month)

*OUTWR* (water right, variable, year, month)

*OUTRES* (reservoir, variable, year, month)

*OUTCPID*(control point)

*OUTWRID*(water right)

*OUTRESID*(reservoir)

The numbers of control points, water rights, and reservoirs included in an OUT file are read from parameters recorded in the fifth record of the OUT file. The total number of control points in the root1.OUT file is not necessarily the same as the number of control points in the root1.HIN file.

The *OUTCP*, *OUTWR*, and *OUTRES* arrays contain the variables listed in Table 4.1 plus associated quantities computed from these variables. Water right *WR* record diversions and instream flow *IF* record reservoir releases (DIV), not listed in Table 4.1, are determined by subtracting shortages (SHT) from targets (TAR). Reservoir storage draw-downs (RSD) are computed as storage capacities (RSC) less storage volumes (STO). *OUTCPID*, *OUTWRID*, and *OUTRESID* arrays contain the identifiers for the control points, water rights, and reservoirs.

Table 4.1  
Variables Read by *HYD* from *SIM* Output OUT File

<u><i>OUT file control point output records</i></u>	<u><i>OUT file water right output records</i></u>
control point identifier	water right identifier
naturalized stream flows (NAT)	water right group identifiers
regulated stream flows (REG)	stream flow depletions for water right (DEP)
unappropriated stream flows (UNA)	return flows for water right (RFL)
stream flow depletions at control point (DEP)	<i>WR</i> diversion or <i>IF</i> release target (TAR)
return flows returned at control point (RFR)	<i>WR</i> diversion or <i>IF</i> release shortage (SHT)
diversion targets (TAR) and shortages (SHT)	instream flow target (IFT)
instream flow target (IFT)	
<u><i>OUT file reservoir output records</i></u>	
reservoir identifier	
net evaporation-precipitation depths before runoff adjustments (EVR)	
net evaporation-precipitation depths after runoff adjustments (EPD)	
reservoir storage volume (STO) and storage capacity (RSC)	

The *OUTCP*, *OUTWR*, and *OUTRES* data arrays read from the root1.OUT file are used within *HYD* in three different alternative ways.

1. An *OI* record writes any of the variables from the root1.OUT input file directly to the root2.HOT output file as records in a specified format.
2. JC(1) and JC(2) option 7 entered on the *JC* record directs that the initial population of the *FLOW* and/or *EP* arrays be from the data in the *OUTCP* and/or *OUTRES* arrays which are accessible to the various routines including *AN* and *EP* record operations.
3. *AS* record fields 5 and 6 control use of the OUT file data for stream flow adjustments. JC(6) can be used to open the OUT file for use in *AS* record operations even if it has not already been opened by JC(1), JC(2), or *OI* records.

The *OI* record is designed to convert *SIM* simulation results to *SIM* or *HYD* input data records. Data from the OUT file arrays are written to the HOT file in a prescribed format. The *OI* record requires no other HIN file input records other than the *JC* record. *CP* records are not required. *CP* records and their control point identifiers are not referenced by the *OI* record operations even if *CP* records are present in the *HYD* input HIN file. The *OI* record outputs the *OUTCP*, *OUTWR*, and *OUTRES* array data in the same sequential order as the control point, water right, and reservoir records are found in the OUT file.

The *OUTCP* and *OUTRES* arrays can also be used to initially populate the *FLOW* and *EP* arrays by specifying JC(1) and/or JC(2) option 7 on the *JC* record. Parameters JC(4) and JC(5) are used to select the variable to be adopted. The *FLOW* array is then used by the other *HYD* operations identically the same as if populated from any other *HYD* input file. The *EP* array is also applied in essentially the same manner regardless of whether initially filled with precipitation-evaporation data from an OUT file or other type of input file. However, the OUT file precipitation-evaporation data are from *SIM* reservoir output records and are referenced by reservoir identifiers. The *AN* and *EP* records can be used with the OUT file precipitation-evaporation data as long as reservoir identifiers are entered on the *CP*, *AN*, and *EP* records rather than control point identifiers.

### **Extending Naturalized Stream Flows**

The original hydrologic periods-of-analysis for the Texas Water Availability Modeling (WAM) System datasets listed in Table 1.2 of Chapter 1 of the *Reference Manual* all begin in either 1934, 1940, or 1948 and end in either 1989, 1996, 1997, 1998, or 2000. Flow extension options are designed for periodically updating the period covered by the naturalized flows to extend to near the present. A methodology for developing naturalized flows from gaged flows is outlined in this section. An alternative flow extension methodology is presented in Chapter 6.

The flow extension methodology presented here is based on using an adjusted current use *SIM* input dataset from the WAM System to convert gaged stream flows to naturalized flows. The WAM System current use scenario is defined in *Reference Manual* Chapter 1. Capabilities are incorporated in *HYD* for performing the computations necessary to implement this strategy.

The naturalized flow datasets for the WAM System were originally developed by adjusting observed flows at gaging stations to remove the effects of historical reservoir storage and operations, water supply diversions, return flows from diversions from surface and ground water sources, and other factors. This same general approach is adopted in the methodology presented in this chapter for extending the period-of-analysis covered by the naturalized flows. However, much time and effort is required to compile and manipulate the voluminous data describing actual water management and use that is required for the flow adjustments. An objective of the alternative approach outlined below is to greatly reduce the required effort by revising the existing current use scenario datasets from the TCEQ WAM System. Program *HYD* provides capabilities for performing the computations.

As an example to illustrate this alternative procedure, assume that the hydrologic simulation period is 1940 through 1997 for a particular river basin. Our hypothetical example dataset has about 1,000 control points of which 50 are primary control points with naturalized flows provided in the *SIM* input. The task addressed here is to develop naturalized monthly flows at the 50 primary control points for the period 1998-2018.

The proposed procedure for extending a naturalized flow dataset to cover the period 1998-2018 at pertinent primary control points consists of combining two datasets.

- 1998-2018 sequences of monthly flows at pertinent gaging stations compiled from available USGS gage records of observed daily flows

- *SIM* input DAT file representing 1998-2018 actual water management and use developed based on modifying the TCEQ WAM System current use input dataset

The procedure consists of adjusting gaged flows at USGS gaging stations with the differences between naturalized (unregulated) flows and regulated flows from a *SIM* simulation with a modified current use dataset. An iterative procedure is required because naturalized flows are computed as a function of flow adjustments but the flow adjustments are computed as a function of naturalized flows. The repetitive procedure may begin with a statistically based set of 1998-2018 naturalized flows determined from the 1940-1997 naturalized flows that serves the sole purpose of determining an initial estimate of stream flow adjustments that are later updated.

The *SIM* simulation with the modified current use DAT input file computes regulated flows allowing the differences between naturalized and regulated flows to be computed by *HYD* for use as adjustments in converting gaged flows to naturalized flows. The accuracy of the procedure depends upon the accuracy of the flow differences rather the accuracy of the naturalized and regulated flows themselves. The stream flows are defined as followed.

*naturalized (unregulated) flows* – gaged flows adjusted to remove the effects of water resources development, management, and use. Naturalized or unregulated stream flows represent natural conditions without the effects of the water resources development, management, and use modeled by the information contained in the *SIM* input DAT file.

*regulated flows* – flows computed by *SIM* by adjusting naturalized flows for the effects of the human activities modeled by the information contained in a *SIM* input DAT file. Regulated flows are the actual flows at a site which would be measured by a stream flow gage if the information in the *SIM* input file perfectly modeled actual water resources development, management, and use during each month of the simulation.

A *SIM* simulation converts naturalized (unregulated) stream flows to regulated stream flows based on the DAT file information describing water resources development, allocation, management, and use. If the *SIM* DAT file reflects actual 1998-2018 conditions, the resulting regulated flows represent actual flows that would be measured by gaging stations.

The difference between *SIM* regulated and naturalized flows at a particular control point consists of the accumulation of stream flow depletions, return flows, reservoir releases, and *CI* and *FA* record flows occurring at that control point and all upstream control points properly cascaded downstream with adjustments for channel losses. Thus, the accuracy of the flow adjustments in the proposed flow extension procedure is basically the accuracy of the *SIM* computation of stream flow depletions, return flows, and reservoir releases.

The *SIM* simulation model is designed to compute regulated flows for given naturalized flows provided as *SIM* input. However, the reverse problem of computing naturalized flows that result in given regulated flows with a given set of water rights requirements is addressed here. *HYD* computes naturalized flows by adding adjustments to actual gaged (regulated) flows. *HYD* reads naturalized river flows, regulated flows, reservoir storage volumes, and storage capacities from an OUT file produced by *SIM* and computes the flow adjustments as follows.

$$\begin{aligned} \text{flow adjustment} &= \text{naturalized flow} - \text{regulated flow} \\ &\quad + \text{storage shortage} + \text{diversion shortage} \end{aligned}$$

The storage and diversion components of the flow adjustments are included to represent actual conditions in the DAT file. The storage shortage is the difference between capacities defined by *SIM* water right storage *WS* and observed storage *OS* records and storage volumes computed by *SIM*. The diversion shortages represent failures to meet the targets specified on water right *WR* and supporting records which may include observed diversions on *TS* records.

Regulated flows are computed from a set of naturalized flows, but regulated flows are required for the flow adjustments used to compute the naturalized flows. Thus, an iterative procedure is required. An initial set of adjustments is developed based on an initial approximation of naturalized flows. These initial flow adjustments are used to convert gaged flows to naturalized flows, which are then used to develop a better estimate of flow adjustments. Programs *HYD* and *SIM* are used in combination to perform the computations.

The proposed procedure for extending a naturalized flow dataset to cover the period 1998-2018 at pertinent primary control points includes the following tasks.

1. Available gaged daily flow data for 1998-2018 at gaging stations are compiled and aggregated to monthly flows. HEC-DSSVue may be used to assist with this task.
2. A set of 1998-2018 monthly net evaporation-precipitation depths are compiled for all pertinent control points that have reservoirs.
3. An actual use *SIM* input dataset is developed that has a 1998-2018 simulation period. The original current use water rights input dataset already approximates 1998-2018 conditions of water resources development, allocation, management and use but may be modified as follows to further improve the representation of actual 1998-2018 conditions.
  - The upstream-to-downstream natural priority option may be adopted to replace the water right permit priorities. This is a simple option switch in *SIM*.
  - Beginning of 1998-2018 simulation reservoir storage volumes are compiled as follows. A *SIM* execution of the modified dataset with the 1940-1997 hydrology results in end-of-simulation December 1997 storage volumes for the many reservoirs recorded in a BES file, which are adopted as beginning of January 1998 storages. For the larger reservoirs, available observations from gage records are used to replace the *SIM* simulated beginning of January 1998 storage volumes.
  - For larger reservoirs with readily available gaged sequences of 1998-2018 end-of-month storage volume observations, the actual storages for all 120 months of the 1998-2018 period-of-analysis can be incorporated into the *SIM* DAT file with observed storage *OS* records. Thus, the *SIM* simulation reproduces actual observed storage contents.
  - Diversion targets and return flows in the DAT file are not changed for many of the water rights due to lack of data, the effort required to update, and minimal impact on final results. However, considering data availability, any number of the larger diversion targets and return flow specifications may be revised with actual 1998-2018 observations. Time series of diversions may be entered on *TS* records or alternatively representative annual water use may be modeled with *WR* and *UC* records.
  - Other modifications may also be made to the DAT file dataset to more closely model actual 1998-2018 water management and use.

4. A FLO file with 1998-2018 naturalized flows is required for the *SIM* input dataset. However, 1998-2018 naturalized flows are the unknown data that the overall procedure is designed to compute. An initial set of 1998-2018 naturalized flows is developed as follows solely for use in developing the initial estimate of flow adjustments. Although mean flows, median flows, or any other exceedance frequency flows could be adopted, the 75 percent exceedance frequency flows are proposed as being reasonably likely flows on the conservatively low side of mean flows. Using the 1940-1997 naturalized flows at a particular control point, the flow volume that is equaled or exceeded in 75% of the 58 years is determined for each of the 12 months January through December. The resulting set of 12 monthly naturalized flow volumes are repeated for each of the ten years during 1998–2018.
5. The *SIM* simulation model is executed with the 1998-2018 period-of-analysis input dataset consisting of the DAT file developed in the preceding Task 3, EVA file from Task 2, and FLO file from Task 4. The objective is to simulate regulated flows that can be used to develop an estimate of flow adjustments consisting of naturalized (unregulated) flows minus regulated flows at the pertinent control points. Storage and diversion shortages determined by *HYD* from the *SIM* simulation results can also be included in the adjustments.
6. Task 6 results in a set of 1998-2018 naturalized flows at the pertinent primary control points. *HYD* reads the *SIM* output OUT file developed as Task 5 and the gaged flows from Task 1. The following computations are performed within *HYD*.
  - Flow adjustments are computed as follows.
 
$$\text{flow adjustment} = \text{naturalized flow} - \text{regulated flow} + \text{storage shortage} + \text{diversion shortage}$$
  - Naturalized flows are computed by adding the flow adjustments to the gaged flows read by *HYD* from another input file.
7. The initial 1998-2018 naturalized flows developed in Task 6 are approximate since the *SIM* simulation of Task 5 is based upon the preceding estimate of naturalized flows. Thus, the tasks 5 and 6 computations are iteratively repeated. The naturalized flows developed in Task 6 are stored as a FLO or DSS file which replaces the *SIM* input file used in Task 5. *SIM* is executed again. The procedure is repeated until the computed regulated flows match the observed gaged flows. At this point in the iterative procedure, changes in the 1998-2018 naturalized flows resulting from subsequent iterations are negligible. The iterations end.

TWRI Technical Report 340 [11] cited at the beginning of this chapter documents a case study application of this flow extension strategy to the WAM dataset for the Brazos River Basin. The methodology is also illustrated by the following simple examples.

#### **Example 4.1 – Applying OI Records**

Examples 4.1 and 4.2 presented here are extensions of Example 2 presented in Chapter 2 of the *Reference Manual*. The results of Example 4.1 are used in Example 4.2.

Example 4.1 consists of converting regulated flows and water supply diversions read from the *SIM* output OUT file for Example 2 of Chapter 2 of the *Reference Manual* to *IN* and *TS*

records written to a *HYD* output HOT file. The *Reference Manual* Example 2 *SIM* simulation creates the *SIM* output OUT file read by *HYD* as the input file HYDexam41.OUT. The regulated flow *IN* records from the file HYDexam41OUT.HOT created in Example 4.1 are adopted in Example 4.2 as the *HYD* input file HYDexam42H.FLO. The *TS* records of water supply diversions are incorporated in the DAT file used in Example 4.2.

Table 4.2  
*HYD* Input HIN File for Example 4.1

```

** WRAP-HYD Input File HYDexam41.HIN
** Example 4.1 from Hydrology Manual
** Regulated flows and diversions read from the OUT file of Reference
** Manual Example are converted to IN and TS records used in Example 4.2.
**      1      2      3
**3456789012345678901234567890123456
JC 2005      3      1      7
**
OI      2      2      IN
OI      7      2      TS      CP2
**
ED

```

Table 4.3  
*HYD* Output HOT File for Example 4.1

WRAP-HYD Output File HYDexam41OUT.HOT

IN	CP1	2005	2586.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN	CP1	2006	0.0	0.0	0.0	0.0	34420.9	64745.7	2215.6	7575.8	15056.0	0.0	0.0	0.0
IN	CP1	2007	0.0	0.0	0.0	0.0	10579.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN	CP2	2005	5086.3	3424.0	1834.0	1000.0	1768.0	1000.0	1000.0	1000.0	2956.0	3736.0	7572.0	3402.0
IN	CP2	2006	3074.0	2974.0	3684.0	7428.0	45188.9	79757.7	1995.6	12167.8	23464.0	6166.0	3442.0	3532.0
IN	CP2	2007	3104.0	4534.0	1354.0	1000.0	16447.6	1000.0	1000.0	1000.0	2998.0	3656.0	6472.0	6772.0
TS	CP2	2005	0.0	0.0	1520.0	3528.0	7220.0	2298.0	2873.0	4111.0	1900.0	380.0	0.0	0.0
TS	CP2	2006	0.0	0.0	1520.0	4560.0	7220.0	8360.0	8360.0	5700.0	1900.0	380.0	0.0	0.0
TS	CP2	2007	0.0	0.0	1520.0	2488.0	7220.0	3602.0	4910.0	5032.0	1900.0	380.0	0.0	0.0

Table 4.4  
*HYD* Message HMS File for Example 4.1

WRAP-HYD MESSAGE FILE

```

*** Starting to read file HYDexam41.HIN
*** JC record was read.
*** Finished reading file HYDexam41.HIN
*****
Number of CP, SV/SA, OI, EP, AN, AS, EQ records read from HIN file.
    0 control point CP records
    0 control points with streamflows read as input
    2 OUT input file OI records
*****
*** Starting OUT file operations.
*** Finished OUT file operations.

***** Normal Completion of Program WRAP-HYD *****

```

### Example 4.2 - Combining SIM and HYD

Both programs *SIM* and *HYD* are applied in the proposed procedure outlined in this chapter for extending naturalized flow sequences. The procedure converts observed gaged flows to naturalized flows. Example 4.2 illustrates the procedure by converting regulated flows from Example 2 of Chapter 2 of the *Reference Manual* to naturalized flows. The regulated flows serve in this example as a surrogate for actual gaged flows. Example 4.2 consists of computing naturalized flows that correspond to given *Reference Manual* Example 2 sequences of regulated flows. Since both naturalized flows and corresponding regulated flows are known, the naturalized flows computed in Example 6 can be compared with the known correct naturalized flows from Example 2. Example 6 consists of computing a set of naturalized flows that will yield the regulated flows from the Example 2 simulation results given the water development, allocation, management, and use reflected in the *Reference Manual* Example 2 DAT file.

The Example 4.2 input files for *SIM* are reproduced as follows. The DAT file from Example 2 of the *Reference Manual* is adopted with the addition of the target series *TS* and observed storage *OS* records. The storages computed in Example 2 are entered on *OS* records. The diversions at control point CP2 computed in *Reference Manual* Example 2 and extracted from the *SIM* OUT file in Example 4.1 are entered on target series *TS* records. Diversions at control point CP1 can be modeled without *TS* records since no shortages occurred in Example 2. The EVA file is adopted from Example 2 without modification. The initial FLO file used in the iterative procedure is reproduced on the next page. The FLO file is revised for each repetition of the iterative computational procedure.

Table 4.5  
*SIM* Input DAT File for Example 4.2

```

T1 WRAP-SIM Input File HYDexam42.DAT
T2 Example 4.2 from Hydrology Manual
**
**      1      2      3      4      5      6      7      8      9      10
**34567890123456789012345678901234567890123456789012345678901234
**      !      !      !      !      !      !      !      !      !      !
JD      3      2005      1      -1
JO      2
**
RO      -1
**
UC munic      0.06      0.06      0.07      0.07      0.08      0.10      0.13      0.12      0.09      0.08      0.08      0.06
UC irrig      0.00      0.00      0.04      0.12      0.19      0.22      0.22      0.15      0.05      0.01      0.00      0.00
**
CP      CP1      CP2      0.08333
CP      CP2      OUT      none
**
IF      CP2      12000      1      Instream Flow
WR      CP2      38000      irrig      3      Irrigation Right
WR      CP2      irrig      3      Irrigation Right
TS      2005      0.0      0.0      1520.0      3528.0      7220.0      2298.0      2873.0      4111.0      1900.0      380.0      0.0
TS      2006      0.0      0.0      1520.0      4560.0      7220.0      8360.0      8360.0      5700.0      1900.0      380.0      0.0
TS      2007      0.0      0.0      1520.0      2488.0      7220.0      3602.0      4910.0      5032.0      1900.0      380.0      0.0
WR      CP1      96000      munic      2      2      0.4      Municipal Right
WS Res-A      110000
**
SV Res-A      0      1030      3730      10800      27700      53400      92100      112000
SA      0      140      409      1150      2210      3100      4690      6160
**
OS Res-A      110000.      108840.103962.5102843.0108273.6      97519.9      83346.3      70695.8      61788.4      55679.7      64177.0      58593.0
OS      2006      55249.6      51641.5      56827.2      91223.0      110000.      110000.      110000.      110000.      110000.109284.4101323.3      95819.8
OS      2007      91823.0      93494.0      86799.8      81110.7      110000.104003.3      97602.5      88227.5      79157.0      71980.3      76647.7      84189.6

```

Table 4.6  
*SIM* Input EVA File for Example 4.2

```

** WRAP-SIM Input File HYDexam46.EVA
** Example 4.2 evaporation-precipitation depths (feet).
EV CP1 2005 3.7 3.9 3.9 3.8 4.2 4.5 4.6 4.3 4.1 3.9 4 3.9
EV CP1 2006 3.6 3.7 3.8 3.6 4.1 4.3 4.4 4.2 4 3.7 3.9 3.7
EV CP1 2007 3.8 3.9 4.0 3.8 4.1 4.2 4.3 4.4 4.2 3.7 4.1 3.7

```

Table 4.7  
Initial *SIM* Input FLO File for Example 4.2

```

** WRAP-SIM Input File HYDexam46.FLO
** Initial naturalized flows (acre-feet/month) set at zero.
**
IN CP1 2005 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
IN CP1 2006 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
IN CP1 2007 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
IN CP1 2005 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
IN CP1 2006 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
IN CP1 2007 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

```

A set of naturalized flows at two control points covering a 36-month simulation period is being developed in this example by applying programs *HYD* and *SIM* in combination. The procedure computes naturalized flows, but naturalized flows are required as input for the *SIM* simulation required by the procedure. Thus, an initial estimate of naturalized flows is developed somewhat arbitrarily to start the computational algorithm. These initially estimated flows are iteratively improved by the modeling algorithm. The FLO file reproduced above contains an initial estimate of zero flow for all 36 months at both control points. Alternatively, the naturalized flows may be initially set at any other amount.

Program *HYD* is executed with HIN, FLO, and OUT input files. The *HYD* input HIN and FLO input files are reproduced below. The regulated flows on *IN* records are excerpted from the file with filename Exam17OUT.HOT created in Example 15 to create the following *HYD* input file with filename HYDexam6H.FLO. The OUT file is generated with program *SIM* with filename HYDexam6.OUT and read by *HYD* as an input file with the filename HYDexam6H.OUT. The HIN and FLO files are fixed as shown below, and the OUT file changes with each iterative execution of *SIM*. *HYD* creates an output file with filename HYDexam6HOUT.FLO that contains the computed naturalized flows. The FLO file created by *HYD* in the final iteration is shown on the next page.

Table 4.8  
*HYD* Input HIN File for Example 4.2

```

** WRAP-HYD Input File HYDexam6H.HIN
**      1      2      3      4      5      6
**3456789012345678901234567890123456789012345678901
JC 2005 3 1 2 0 1 0 0 1 0 2
CP CP1 CP2
CP CP2 OUT
AS CP1 0 0 5 1 0 1
AS CP1 0 0 5 2 0 1 0 -1.0

```

AS	CP1	0	0	5	14	0	0	0	1.0	Res-A
AS	CP1	0	0	5	8	0	0	0	1.0	
AS	CP2	0	0	5	1	0	1	0	1.0	
AS	CP2	0	0	5	2	0	1	0	-1.0	
AS	CP2	0	0	5	8	0	0	0	1.0	
ED										

**Table 4.9**  
**HYD Input FLO File for Example 4.2**

```

** WRAP-HYD Input File HYDexam42FLO
** Example 4.2gulated flows (acre-feet/month).
**
IN  CP1  2005  2586.3    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
IN  CP1  2006    0.0    0.0    0.0    0.0  34420.9  64745.7  2215.6  7575.8 15056.0    0.0    0.0    0.0    0.0
IN  CP1  2007    0.0    0.0    0.0    0.0  10579.6    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
IN  CP2  2005  5086.3  3424.0  1834.0  1000.0  1768.0  1000.0  1000.0  1000.0  2956.0  3736.0  7572.0  3402.0
IN  CP2  2006  3074.0  2974.0  3684.0  7428.0  45188.9  79757.7  1995.6 12167.8 23464.0  6166.0  3442.0  3532.0
IN  CP2  2007  3104.0  4534.0  1354.0  1000.0  16447.6  1000.0  1000.0  1000.0  2998.0  3656.0  6472.0  6772.0

```

**Table 4.10**  
**Final HYD Output FLO File for Example 4.2**

```

WRAP-HYD Output File HYDexam6HOUT.FLO
IN  CP1  2005 10200.0  6540.0  3710.0  7350.0 15100.0   904.1   112.0   328.0   972.0 2650.0 17300.0 1290.1
IN  CP1  2006  3390.0  3110.0 12900.0 42300.0 62700.0 76500.0 16900.0 21200.0 25700.0 8809.9 1560.1 1849.9
IN  CP1  2007  3290.0  8970.1 1569.9  2410.1 48900.0  5630.0  7990.1  3910.0 1090.0 1739.9 13700.1 14600.0
IN  CP2  2005 12700.0  7660.0  4760.0  9190.0 21400.0 1130.1   145.0   447.0 1220.0 3310.0 21800.0 1620.1
IN  CP2  2006  4160.0  3780.0 15800.0 51600.0 78000.0 96800.0 21200.0 26500.0 31400.0 11899.9 1930.1 2309.9
IN  CP2  2007  4090.0 11200.1  2139.9  3210.1 59300.0  7160.0 10060.1  4950.0 1380.0 2319.9 17100.1 18300.0

```

In an actual application of the procedure illustrated by Example 4.2 the objective would normally be to estimate naturalized flows corresponding to observed gaged flows. However, the example consists of estimating naturalized flows for given regulated flows and comparing the results with the correct known naturalized flows. The example starts with both given naturalized and regulated flows. Naturalized flows are computed for given regulated flows with water resources development, management, allocation, and use represented by the information provided by the DAT file. The iterative computational procedure consists of the following steps.

Step 1: The procedure begins with an assumed set of naturalized flows. Essentially any set of assumed naturalized flows will work for this example. However, zero was arbitrarily adopted as an initial estimate for the naturalized flows for all 36 months at both control points. The naturalized flows are input to *SIM* as a FLO file.

Step 2: *SIM* is executed with the DAT, EVA, and FLO files with the original data.

Step 3: The naturalized flow, regulated flow, reservoir storage volume, and reservoir storage capacity (*OS* records) are read by *HYD* from the OUT file produced by *SIM*. *HYD* computes the flow adjustments for each of the 36 months at each of the two control points.

$$\begin{aligned} \text{flow adjustment} &= \text{naturalized flow} - \text{regulated flow} \\ &\quad + \text{storage shortage} + \text{diversion shortage} \end{aligned}$$

Step 4: *HYD* computes updated naturalized flows by adding flow adjustments defined by HIN file *AS* records to the original regulated flows. The resulting naturalized flows are recorded in a file with filename *HYDexam42HOUT.FLO*, which is converted to a *SIM* input *FLO* file by removing the header and changing the filename.

Step 5: Steps 2, 3, and 4 are repeated with the updated estimate of naturalized flows. The procedure is repeated until the naturalized flows no longer change between iterations.

The naturalized flows resulting from three iterations are tabulated on the next page along with the initial estimate and correct naturalized flows from the *Reference Manual* example. Three consecutive updates of the naturalized flows are tabulated. The procedure stopped after the third update since the results were the same for the second and third iterations and additional changes do not occur with further iterations. For this simple example, the procedure results in perfectly correct naturalized flows in all months at both control points in two iterations starting with zero flows for all months. If the procedure is initiated with the actual correct naturalized flows, the computed flows are these same correct naturalized flows.

For this simple example, the procedure results in the correct final naturalized flows regardless of the initial estimate of naturalized flows. If the naturalized flows at all control points for all months are initially set at zero, the procedure converges to the correct values in two iterations. If the naturalized flows at all control points for all months are initially set at a large value such as 50,000 acre-feet/month, the procedure results in the correct values (to the nearest acre-foot) in the initial simulation without requiring a second repetition. If the flows are set at the 3-year means of each of the 12 months of the year, the correct flows are achieved in two iterations. For other more complex datasets, more repetitions will be required and the number of repetitions will be more sensitive to the initially assumed values for the naturalized flows.

#### Example 4.2 Summary

The *SIM* simulation model is designed to compute regulated stream flows for given naturalized stream flows provided as *SIM* input. In a *SIM* simulation, the water rights and related river/reservoir system management information in the *DAT* file convert naturalized flows entered in the *FLO* input file to regulated flows recorded in the *OUT* output file. However, Example 6 solves the reverse problem of computing naturalized flows that result in given regulated flows with a given set of water rights requirements. Naturalized flows are computed in Example 4.2 given the regulated flows and water rights data from *Reference Manual* Example 2.

The *SIM DAT* file from *Reference Manual* Example is adopted for Example 4.2 along with the addition of sets of *TS* and *OS* records. The junior irrigation right incurs shortages in the original *Reference Manual* Example 2. Thus, *TS* records are used for this water right in Example 4.2 to reproduce the diversions in each of the 36 months. The senior municipal water right incurs no diversion shortages in *Reference Manual* Example 2 and is thus modeled with only the conventional *WR* and *WS* records in Example 4.2.

Observed storage *OS* records are inserted into the Example 4.2 *DAT* file to reproduce the *Reference Manual* Example 2 end-of-month storage volumes in each of the 36 months. The *OS* record storage levels are capacities to which storage is refilled constrained by the availability of

stream flow. If the initial estimates of naturalized flow entered in the original FLO input file are too small, the storage levels on the *OS* records will not be reached. Thus, additional repetitions of the computational procedure may be required.

Table 4.11  
Naturalized Flows at Control Points CP1 and CP2 Computed in  
Each of 3 Iterations Compared with Initial and Correct Quantities

Year	M	Naturalized Flows at CP1 (acre-feet)					Naturalized Flows at CP1 (acre-feet)				
		Initial	1	2	3	Correct	Initial	1	2	3	Correct
2005	1	0.0	10,114	10,200	10,200	10,200	0.0	12,614	12,700	12,700	12,700
2005	2	0.0	13,812	6,540	6,540	6,540	0.0	14,932	7,660	7,660	7,660
2005	3	0.0	17,178	3,710	3,710	3,710	0.0	18,228	4,760	4,760	4,760
2005	4	0.0	24,142	7,350	7,350	7,350	0.0	25,982	9,190	9,190	9,190
2005	5	0.0	38,636	15,100	15,100	15,100	0.0	44,936	21,400	21,400	21,400
2005	6	0.0	38,811	904	904	904	0.0	39,037	1,130	1,130	1,130
2005	7	0.0	38,292	112	112	112	0.0	38,325	145	145	145
2005	8	0.0	38,092	328	328	328	0.0	38,211	447	447	447
2005	9	0.0	38,560	972	972	972	0.0	38,808	1,220	1,220	1,220
2005	10	0.0	40,675	2,650	2,650	2,650	0.0	41,335	3,310	3,310	3,310
2005	11	0.0	57,212	17,300	17,300	17,300	0.0	61,712	21,800	21,800	21,800
2005	12	0.0	57,533	1,290	1,290	1,290	0.0	57,863	1,620	1,620	1,620
2006	1	0.0	59,971	3,390	3,390	3,390	0.0	60,741	4,160	4,160	4,160
2006	2	0.0	57,402	3,110	3,110	3,110	0.0	59,960	3,780	3,780	3,780
2006	3	0.0	63,547	12,900	12,900	12,900	0.0	68,751	15,800	15,800	15,800
2006	4	0.0	97,943	42,300	42,300	42,300	0.0	109,931	51,600	51,600	51,600
2006	5	0.0	152,101	62,700	62,700	62,700	0.0	170,089	78,000	78,000	78,000
2006	6	0.0	184,346	76,500	76,500	76,500	0.0	207,718	96,800	96,800	96,800
2006	7	0.0	124,696	16,900	16,900	16,900	0.0	132,836	21,200	21,200	21,200
2006	8	0.0	129,096	21,200	21,200	21,200	0.0	139,388	26,500	26,500	26,500
2006	9	0.0	133,696	25,700	25,700	25,700	0.0	144,004	31,400	31,400	31,400
2006	10	0.0	116,964	8,810	8,810	8,810	0.0	123,510	11,900	11,900	11,900
2006	11	0.0	109,003	1,560	1,560	1,560	0.0	112,445	1,930	1,930	1,930
2006	12	0.0	101,580	1,850	1,850	1,850	0.0	105,112	2,310	2,310	2,310
2007	1	0.0	97,583	3,290	3,290	3,290	0.0	100,687	4,090	4,090	4,090
2007	2	0.0	99,254	8,970	8,970	8,970	0.0	103,788	11,200	11,200	11,200
2007	3	0.0	93,520	1,570	1,570	1,570	0.0	96,394	2,140	2,140	2,140
2007	4	0.0	87,831	2,410	2,410	2,410	0.0	91,319	3,210	3,210	3,210
2007	5	0.0	128,260	48,900	48,900	48,900	0.0	141,348	59,300	59,300	59,300
2007	6	0.0	113,603	5,630	5,630	5,630	0.0	118,205	7,160	7,160	7,160
2007	7	0.0	110,083	7,990	7,990	7,990	0.0	115,993	10,060	10,060	10,060
2007	8	0.0	99,748	3,910	3,910	3,910	0.0	105,780	4,950	4,950	4,950
2007	9	0.0	87,797	1,090	1,090	1,090	0.0	92,695	1,380	1,380	1,380
2007	10	0.0	79,660	1,740	1,740	1,740	0.0	83,696	2,320	2,320	2,320
2007	11	0.0	84,328	13,700	13,700	13,700	0.0	90,800	17,100	17,100	17,100
2007	12	0.0	89,950	14,600	14,600	14,600	0.0	96,722	18,300	18,300	18,300

Program *HYD* adjusts the regulated flows to obtain naturalized flows by activating options defined by the *JC* and *AS* records in the HIN file. *HYD* reads naturalized flows, regulated flows, diversion shortages, and reservoir storage volumes and capacities from the OUT

file produced by *SIM* and computes flow adjustments as follows for the 36 months at the two control points.

$$\begin{aligned}\text{flow adjustment} = & \text{naturalized flow} - \text{regulated flow} \\ & + \text{storage shortage} + \text{diversion shortage}\end{aligned}$$

The storage shortage component of the flow adjustment is the difference between the capacities defined by the *SIM WS* and *OS* records and storage volumes computed by *SIM*. The diversion shortages represent failures to meet the targets on the *WR* and *TS* records. *HYD* adds the flow adjustments to the given regulated flows to obtain the naturalized flows tabulated in Table 4.11.

### **Developing a Condensed *SIM* Input Dataset**

The larger Texas WAM System datasets contain hundreds of water rights, control points, and reservoirs. These large complex datasets are necessary for the regional and statewide planning and water right permitting applications for which the datasets were developed. However, simpler datasets are advantageous for certain other applications. A methodology is introduced here for condensing *SIM* input datasets for particular applications. Many of the water rights, control points, and reservoirs are removed from the DAT file with their effects retained in the adopted stream inflow input data recorded in the FLO file. TWRI Technical Report 340 [11] cited at the beginning of this chapter explains the procedure for developing a condensed dataset, illustrates the *HYD* and *SIM* computations with a simple hypothetical example, and then applies the procedure to develop a condensed dataset from the Brazos River Basin WAM.

For purposes of this discussion, assume that a large *SIM* input dataset contains 1,650 diversions, 510 reservoirs, and 2,150 control points. Naturalized flows are input on inflow *IN* records for 32 primary control points located at gaging stations and distributed within *SIM* to the other 2,118 ungaged secondary control points. The hydrologic period-of-analysis is 1940-2007.

A water management agency operates a system of ten reservoirs in this river basin with 25 water supply diversions occurring at the ten reservoirs and five other downstream control points. This particular system of interest is a component part of the larger complete dataset. A condensed DAT file is developed that contains only the 15 control points, 10 reservoirs, and 25 diversion rights. Impacts of the other 500 reservoirs and 1,625 diversion rights are reflected in the *IN* record river flows in the FLO file developed for the condensed *SIM* input dataset.

The objective is to develop a condensed *SIM* input dataset for purposes of studying or providing decision support for a particular system, called the primary system, which in this example consists of ten reservoirs and 25 diversions with associated river/reservoir/use system operating rules. The effects of all the water rights, called secondary rights, with associated reservoirs and control points, removed from the DAT file are reflected in the inflows in the FLO file. The motivation is that input datasets and corresponding output datasets with dramatically fewer control points, water rights, and reservoirs are much more manageable to use in modeling studies. Also, alternative operating strategies for the primary system can be modeled based on only the aggregated stream flows available to the primary system, while preserving secondary water rights. The simplified dataset is our example consists of the following *SIM* input files.

- DAT file with information for ten reservoirs and 25 diversions at 15 control points
- FLO or DSS file with 1940-2007 sequences of monthly flows representing conditions of river system development that includes all of the water rights and associated reservoirs in the original complete DAT file except the 25 diversions and ten reservoirs contained in the simplified dataset DAT file
- EVA or DSS file with 1940-2007 sequences of monthly net evaporation-precipitation depths for the ten control points at which the ten reservoirs are located
- An optional RUF file also may be included to incorporate conventional regulated flows but is not necessarily required.

The procedure as outlined here is based on reproducing unappropriated flows. Regulated flows can also be reproduced using a regulated-unappropriated flow RUF file. Particular applications of condensed datasets may or may not require inclusion of the optional RUF file.

The simplified dataset should adopt the same net evaporation-precipitation depths for the ten reservoirs as used in the original complete dataset *SIM* simulation. *SIM* includes an option for adjusting net evaporation-precipitation depths for the precipitation runoff from the portion of the watershed covered by the reservoir. In this case, net evaporation-precipitation depths should be obtained from the OUT file for the complete simulation rather than using the original evaporation-precipitation depth input dataset.

The input data vary as follows between the original and condensed *SIM* input datasets.

- In the original complete input dataset, the stream flows at the 32 primary control points provided on inflow *IN* records in a FLO file are naturalized flows representing river basin hydrology under natural conditions with no reservoirs and no diversions. The DAT input file contains 2,150 control points, 1,650 diversion rights, and 510 reservoirs. Watershed parameters are provided in a flow distribution DIS file for the 2,118 secondary control points.
- In the condensed dataset, the stream flows at the 15 primary control points provided on the FLO file *IN* records represent conditions with the 500 reservoirs and 1,625 diversions that were removed from the DAT file being in operation but without the others that remain in the DAT file. The DAT input file contains 15 control points, 25 diversion rights, and 10 reservoirs. There is no DIS file. An optional RUF file allows determination of regulated flows based on adjusting unappropriated flows.

The accuracy achieved in the development of a simplified dataset can be checked by comparing simulation results with the original complete dataset. With the primary system operated the same, the diversion amounts and reliabilities computed for the diversions included in the condensed dataset should be the same as in the simulation with the original complete dataset. Likewise, the 1940-2007 sequences of reservoir storage volumes and unappropriated stream flows at the 15 control points will be the same. Near perfect correspondence between simulation results with the simplified versus complete datasets should be expected.

The methodology for developing a simplified condensed dataset is based on developing flows at the selected control points that represent stream inflow amounts available to the selected system that reflect the impacts of all of the water rights and accompanying reservoirs removed from the original complete dataset. Stream flows are provided on *IN* records in either a FLO input file or a hydrology input DSS file for the condensed dataset. These stream flows represent flows available to the selected primary system modeled in the water right DAT input file considering the effects of all the other secondary water rights in the river basin contained in the original complete DAT file that are not included in the condensed DAT file.

The stream inflows input on *IN* records in a FLO file or DSS records in a DSS file for the condensed dataset include stream flow depletions made for the selected water rights less return flows plus unappropriated flows. Hydropower releases and reservoir releases made specifically to meet instream flow requirements are also appropriately incorporated in the flows. Summation and cascading operations are applied in developing the stream flow input data. The methodology for developing the stream flow data (FLO or DSS file) for the simplified condensed dataset is outlined as follows.

1. *SIM* is executed with the original complete dataset.
2. *HYD* is applied to read pertinent stream flow depletions, return flows, unappropriated flows, and any other pertinent variables from the *SIM* output OUT file and combine these variables as required to develop the stream flow FLO or DSS input file for the condensed dataset. Combining the time sequences of flow volumes include summations and cascading operations that may include channel losses. *HYD* reads the necessary control point information from an input file. Options are also provided in *HYD* for dealing with the issue of computed flows being negative numbers.

Referring again to the example, stream flows developed for the 15 control points consist of the following 1940-2007 sequences of monthly volumes of the following variables obtained from the OUT file created by *SIM* with the original complete input dataset. The computations can be performed with *HYD*.

- Stream flow depletions made by each of the 25 water rights with their 10 reservoirs are included in the flows being developed. These flow volumes are placed at the control point of the stream flow depletion and at all downstream control points. Channel losses are considered in cascading the stream flow depletions downstream.
- Return flows from the diversion component of the stream flow depletions are subtracted from the flows. These flow volumes are placed at the control point at which the return flow is returned to the stream and at all downstream control points. Channel losses are considered in cascading the return flows downstream.
- Unappropriated flows at each of the 15 control points are added to the flows. Since unappropriated flows are cumulative total flows, these flows are not cascaded downstream
- Any releases from the 10 selected reservoirs made specifically for instream flow rights are subtracted at the control point of the reservoir and cascaded downstream in

the normal manner which includes consideration of channel losses. Hydroelectric power releases from the 10 selected reservoirs are likewise subtracted and cascaded.

The accuracy of the procedure is confirmed by reproducing the sequences of monthly diversions, storage contents, unappropriated flows, and other pertinent variables contained in the *SIM* simulation results associated with the ten reservoirs, 25 diversions, and 15 control points. These *SIM* simulation results should be same with the condensed dataset versus the original complete dataset. The system of ten reservoirs and 25 diversions must be operated the same in both the simplified and complete datasets for the comparison simulations. After completing the comparison to confirm that the dataset is correct, the simplified condensed dataset can be used to simulate alternative river/reservoir system operating rules and water management and use scenarios for the system of ten reservoirs and associated diversions at the 15 control points.

## CHAPTER 5

### EXTENSION OF NET EVAPORATION-PRECIPIATION RATES

The Texas Water Development Board (TWDB) maintains datasets of historical observed monthly precipitation depths and reservoir surface evaporation depths for a grid of one-degree quadrangles covering Texas which are described in Chapter 2 of this manual. The observed precipitation and evaporation rates begin in 1940 and are updated by the TWDB each year. These TWDB datasets were used along with other observed evaporation and precipitation measurements to develop the original files of net evaporation less precipitation rates included in the TCEQ WAM System. The basis of the hydrologic period-of-analysis extension strategy presented in Chapters 5 and 6 is to use the datasets of precipitation and evaporation compiled by the TWDB combined with TCEQ WAM datasets of naturalized flows to extend naturalized flows along with net evaporation-precipitation rates.

The TWDB datasets of monthly precipitation depths and reservoir surface evaporation depths in inches for the quadrangles delineated on the map of Figure 2.1 and explanation of methods employed in compiling the data are available at the following website.

<http://www.twdb.state.tx.us/surfacewater/conditions/evaporation/index.asp>

Chapter 2 describes the TWDB database of monthly evaporation and precipitation depths. Chapters 5 and 6 describe features added to *HYD* for updating the hydrologic periods-of-analysis of the WAM datasets using the TWDB quadrangle evaporation and precipitation datasets. Chapter 5 describes *HYD* features for compiling *SIM* input *EV* records of net evaporation less precipitation depths from the TWDB datasets. Chapter 6 explains *HYD* features that use the TWDB evaporation and precipitation datasets to extend the naturalized stream flow sequences in the WRAP input FLO files of the WAM datasets. *HYD* input records used to apply the capabilities presented in Chapters 5 and 6 are described in Chapter 8.

#### **Extension of Net Evaporation-Precipitation Rates**

The hydrology input data for the WRAP simulation program *SIM* includes monthly net reservoir surface evaporation less precipitation depths on *EV* records in an EVA file along with the naturalized flows on *IN* records in a FLO file. The evaporation-precipitation rates in the TCEQ WAM System datasets are in units of feet/month. The evaporation-precipitation rates are computed using the TWDB datasets by subtracting precipitation depths from evaporation depths. EVA files of *EV* records may be compiled alternatively using either options described earlier in Chapter 3 or the options outlined as follows in this chapter.

The features initially incorporated in *HYD* to create hydrology files for original new WRAP input datasets are documented in Chapter 3 and are implemented using *HYD* input records described in Chapter 7. Capabilities added to *HYD* during 2011-2013 for extending hydrologic periods-of-analysis of existing datasets are covered in Chapters 5 and 6 and are controlled by *HYD* input records described in Chapter 8.

Program *HYD* is applied with *JC*, *CP*, *EE*, *EX*, *QD*, and *QA* records to update a *SIM* input EVA file. The evaporation extension *EE* record provides specifications for *HYD* to manipulate the data read from the statewide TWDB evaporation and precipitation databases stored in *HYD*

input files with filenames Precipitation.PPP and Evaporation.EEE. *JC* and *CP* records are included in Chapter 7. *EE*, *EX*, *QD*, and *QA* records are covered in Chapter 8.

The option switch EE in *EE* record field 6 activates the creation of the following monthly data sequences.

1. evaporation less precipitation depths in inches
2. precipitation depths in inches
3. evaporation depths in inches
4. evaporation less precipitation volumes in acre-feet
5. precipitation volumes in acre-feet
6. evaporation volumes in acre-feet
7. evaporation depths in inches less a monthly-varying factor multiplied by precipitation depths in inches

The multiplier factor EEX entered in *EE* record field 8 can be used for unit conversions. For example, an EEX of 0.083333 converts depths from inches to feet. The EEX default of 1.0 results in units of inches and acre-feet as noted above. EE option 7 applies multiplier factors from an *EX* record that are designed to adjust precipitation to reflect runoff at a reservoir site.

The default EE option 1 will normally be adopted for extending EVA files. *EV* records with net reservoir surface evaporation less precipitation depths are created. The other extra EE options may be useful for various investigations though not actually required for extending WAM datasets. EE options 1, 2, 3, or 7 may be applied with a single quadrangle, with the quadrangle identifier QD1 entered in *EE* record field 7. EE options 1, 2, 3, 4, 5, 6, or 7 may be applied with any number of quadrangles with the quadrangle identifiers entered on a *QD* record.

Quadrangle identifiers are listed on a *QD* record, and either areas or multiplier factors for each quadrangle are listed on a *QA* record. The following three alternative options are activated by the option switch AA in *QA* record field 2.

1. watershed areas in square miles are entered on the *QA* record
2. areas in square miles are computed by *HYD* using factors entered on the *QA* record that represent the fraction of each quadrangle encompassed by the watershed
3. factors are entered on the *QA* record for use in computing weighted averages of net evaporation less precipitation, evaporation, or precipitation depths

AA options 1 and 2 are designed to be used with *FE* records in extending naturalized flows but can also be used with EE options 4, 5, and 6. AA option 3 is designed to be used with EE options 1, 2, and 3. With AA option 3, the numbers on the *QA* record are summed, and each number is divided by the summed total. Each quadrangle is thus assigned a fraction between 0.0 and 1.0. The fractions total to 1.0. These fractions are multiplier factors used to compute weighted averages of the precipitation and evaporation data.

Most *HYD* computational capabilities use one or both of the following arrays which store data in computer memory with data modifications as computations are performed.

FLOW(cp,year,month) array which contains monthly stream flow volumes  
EP(cp,year,month) array which contains monthly evaporation-precipitation rates

At the beginning of a *HYD* execution, the known naturalized flows are read from a FLO file and stored in the FLOW array, and/or net evaporation-precipitation rates are read from an EVA file and stored in the EP array. The FLOW array remains populated with the original known flows until overwritten by computed flows. Likewise, the EP array keeps the original net evaporation-precipitation rates unless overwritten by computed net evaporation-precipitation rates. At the end of the *HYD* execution, the flows in the FLOW array are written to an output FLO or DSS file, and likewise the net evaporation-precipitation rates in the EP array are written to an output EVA or DSS file. *JC* record options control transferring data between FLO, EVA, and DSS files and the FLOW and EP arrays stored in active computer memory.

For example, a 1990-1997 hydrologic period-of-analysis may be extended to include 1998-2012. The FLOW array at the end of a *HYD* execution will contain the original naturalized flows read for 1940-1997 and synthesized flows for 1998-2012. Likewise, the EP array at the end of a *HYD* execution will contain the original evaporation-precipitation rates for 1940-1997 and computed evaporation-precipitation rates for 1998-2012. These data are written from the FLOW and EP arrays to FLO, EVA, and/or DSS files as controlled by options on the *JC* record.

### **Example 5.1 – Net Evaporation-Precipitation Rates**

Application of *HYD* with the TWDB precipitation and evaporation datasets to extend the hydrologic period-of-analysis of a WRAP-SIM simulation input dataset is illustrated by the following evaporation-precipitation extension example and a much more complex naturalized flow extension example presented in the next chapter. The *HYD* input records applied in these examples are described in Chapter 8. Both of these examples are derived from a case study using the Brazos River Basin WAM [11].

In this example, *HYD* reads HIN, PPP, and EEE input files and outputs a message HMS file. The HIN and HMS files are presented on the following pages as Tables 5.1 and 5.2. Other *HYD* input and output files can also be added as noted in the next paragraph.

Precipitation.PPP	TWDB 1940-2012 precipitation for all Texas quadrangles
Evaporation.EEE	TWDB 1940-2012 evaporation for all Texas quadrangles
HYDexam7.HIN	<i>HYD</i> input HIN file for this example
HYDexam7.HMS	<i>HYD</i> output message file for this example

A *JC* record is required for all HIN files. The *JC* record for this example is very simple with most fields left blank. However, other input and output file options can be activated on the *JC* record. For example, an entry in *JC* record field 13 (nonzero *JC*(9)) would store the *EV* records created in the example as either a EVA, HOT, or DSS file in a specified format. Original *EV* records for 1940-1997 can be included in the EVA or DSS file along with the *EV* records created for 1998-2012 by adding a FLO input file with 1940-1997 *EV* records, entering 1940 and 58 years for YRST and NYRS in *JC* record fields 2 and 3, and a non-zero entry for *JC*(2) in *JC* record field 6.

The three *EE* records in the HIN file develop data for control points EP710, EPCOM, and PCOM. The first *EE* record reads the evaporation and precipitation rates for 1998-2012 for quadrangle 710 from the EEE and PPP files and computes the net evaporation minus

precipitation for each month. The resulting net evaporation-precipitation rates in inches are recorded in the HMS file of Table 5.2 in *EV* record format. The HMS file also shows the means of the 1998-2012 monthly evaporation and precipitation rates of 4.56 and 2.76 inches along with the mean of 1.80 inches for the computed net evaporation-precipitation rates.

Table 5.1  
*HYD* Input HIN File for Evaporation-Precipitation Example

```

** WRAP-HYD Input File HYDexam51.HIN
**      1      2      3      4
**3456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !
JC  1998  15    1
CP  EP710
CP  EPCOM
CP  PCOM
EE  EP710      710      1998      2012      2    1
EE  EPCOM      1998      2012      2    1
QD      4      609      610      709      710
QA      3      0.25      0.25      0.25      0.25
EE  PCOM      1998      2012      2    6
QD      4      609      610      709      710
QA      2      1.0      1.0      1.0      1.0
ED

```

The second *EE* record, also activating *EE* option 1, and auxiliary *QD* and *QA* records develop *EV* records with the weighted average of the net evaporation less precipitation rates for quadrangles 609, 610, 709, and 710. *AA* option 3 is specified in *QA* record field 2 to activate the weighted-average option. The number 0.25 is entered on the *QA* record for each of the four quadrangles listed on the *QD* record. However, the same results will be obtained with any number other than 0.25 as long as the same number is assigned to all four of the quadrangles.

The third *EE* record and auxiliary *QD* and *QA* records activate *EE* option 6 to develop total precipitation volumes in acre-feet/month for quadrangles 609, 610, 709, and 710. *AA* option 2 in *QA* record field 2 applies the areas from Table 4.1, which total to 16,284 square miles for the four quadrangles, in the volumes computation. Precipitation volumes are computed as precipitation depths multiplied by quadrangle areas.

The summary of results for the second *EE* record includes an 1998-2012 average precipitation depth for the four quadrangles of 2.6251 inches. This depth multiplied by the 16,284 square mile area of the four quadrangles results in the mean monthly precipitation volume of 2,279,870 acre-feet recorded in the *EP* array as shown in the HMS file of Table 5.2.

Table 5.2  
HYD Output Message HMS File for Evaporation-Precipitation Example

```

WRAP-HYD MESSAGE FILE

*** Starting to read file HYDexam7.HIN
*** JC record was read.
*** Starting to read CP records.
*** Finished reading CP records.
*** Finished reading file HYDexam7.HIN
*****
Record counts for selected HIN file record types.
  3 control point CP records
  3 control points with streamflows read as input
  3 evaporation extension EE records
*****
*** Starting hydrologic period-of-analysis extension routine.
*** EE record was read for control point EP710.
*** Starting to read PPP and/or EEE files.
*** Finished reading Precipitation.PPP file.
*** Finished reading Evaporation.EEE file.

EP Array Created with EE Record for Control Point EP710
Extension Period 1998-2012
Mean Evaporation Depth (inches/month)    =  4.5618
Mean Precipitation Depth (inches/month)   =  2.7622
Mean of EP Array Depths                   =  1.7996

EV EP710  1998 -0.8500 -1.7300  1.4900  3.8700  4.8800  6.7400  7.0000  3.8000 -0.8800 -6.3700 -1.6700  0.1500
EV EP710  1999  1.5100  2.3800  0.3400  2.8800  0.3900  3.2700  3.7600  6.6400  5.0300  2.6300  2.8100  0.7300
EV EP710  2000 -1.1800  0.7300  1.7800  2.0500  0.5800  2.3200  7.7300  7.1900  3.3800 -0.2400 -5.5900 -0.6000
EV EP710  2001 -1.5300  0.8500 -2.8000  2.3300  0.7700  3.5900  5.5500  1.2200  1.4500  1.4700 -2.7500 -2.5100
EV EP710  2002  1.0400  1.5700  1.8200  3.0700  4.4000  2.1900  0.2300  6.0000  2.2800 -3.2200 -0.5200 -2.6300
EV EP710  2003  0.0200 -3.4500  1.7900  4.1100  3.1900  1.4600  3.2600  5.4500  1.6500  1.3100  1.2000  1.3800
EV EP710  2004 -2.4000 -2.7600  0.9300 -1.1700  0.8000 -6.6300  4.0200  2.5300  3.4500 -4.2500 -7.8900  1.1300
EV EP710  2005 -0.8200 -0.6400  1.0000  4.0500  0.6100  5.8000  3.2800  2.1700  5.7900  3.7600  3.2800  3.0900
EV EP710  2006  2.9800  1.0700  1.2200  2.3300  2.6500  3.0200  5.2400  7.3600  2.6300 -0.9500  3.2700 -0.9100
EV EP710  2007 -4.4100  3.5500 -4.6700  1.4400 -4.0300 -2.1000 -3.8800  4.2700  2.2200  3.3600  1.1300  1.6500
EV EP710  2008  1.4900  2.6400  0.2200  1.2900  2.7200  7.1800  7.7000  4.4200  6.0000  3.5500  3.1000  2.6500
EV EP710  2009  2.7500  2.9800  1.7600  1.5500  2.9300  7.9700  7.7600  7.7500 -4.2200 -5.1000 -0.3100  0.0500
EV EP710  2010 -0.9000 -1.3100  0.8700  2.1300  3.1800  2.2600  2.3200  7.0500 -2.9200  5.0500  2.8400  2.2800
EV EP710  2011  1.0400  1.4800  4.2000  5.2100  4.2900  7.6500  8.4600 10.1400  7.4800  3.3900  1.3100 -2.9900
EV EP710  2012 -1.5000 -1.8000 -2.9100  4.5500  0.6700  5.3400  1.7700  5.5600  1.2500  2.0700  3.7000  2.1200

*** EE record was read for control point EPCOM.
*** QD record was read for control point EPCOM.
*** QA record was read for control point EPCOM.
*** Starting to read PPP and/or EEE files.
*** Finished reading Precipitation.PPP file.
*** Finished reading Evaporation.EEE file.

EP Array Created with EE Record for Control Point EPCOM
Extension Period 1998-2012
Mean Evaporation Depth (inches/month)    =  4.7850
Mean Precipitation Depth (inches/month)   =  2.6251
Mean of EP Array Depths                   =  2.1599

```

Table 5.2 Continued  
HYD Output Message HMS File for Evaporation-Precipitation Example

EV EPCOM	1998	-0.6150	-1.6950	0.3950	3.6975	4.3925	5.8900	6.2550	3.4400	1.0825	-3.4625	-0.6200	-0.2950
EV EPCOM	1999	1.4700	2.3475	0.3400	2.6975	0.4600	4.0000	4.8000	7.3725	5.3000	2.7225	3.2200	0.9825
EV EPCOM	2000	0.7250	0.9725	2.5750	2.8100	1.8075	2.7075	8.7475	8.2900	4.5175	0.2925	-3.7350	0.4125
EV EPCOM	2001	-1.1925	0.0125	-1.5175	2.5925	1.7675	5.0625	7.2850	3.1525	1.7875	1.9650	-2.4850	-0.9700
EV EPCOM	2002	1.0000	0.9525	1.3950	3.5800	3.0425	3.2800	-1.9550	6.1500	3.4250	-2.0225	1.7000	-1.3075
EV EPCOM	2003	0.9500	-1.8525	2.1125	4.5575	3.0425	0.2100	5.0225	5.1225	0.4375	0.5700	2.4850	2.6000
EV EPCOM	2004	-0.8275	-1.7150	0.9625	-2.0275	1.8125	-4.8425	4.6800	1.6400	4.0550	-2.0225	-6.6375	1.5425
EV EPCOM	2005	0.0125	-0.5300	1.7500	4.8500	0.6400	6.2225	5.3200	2.3600	6.0750	3.9400	3.7350	3.1225
EV EPCOM	2006	2.6350	1.8225	1.3825	3.1525	2.8575	5.0100	6.9525	7.8725	3.5950	1.0475	3.2850	0.7750
EV EPCOM	2007	-2.3250	3.0150	-4.3625	2.0250	-4.9475	-3.3050	-1.0900	4.1150	1.7225	3.8000	1.7500	2.2175
EV EPCOM	2008	2.3100	3.0725	1.2800	1.7725	3.2625	7.2800	7.1800	3.4550	5.2225	2.8525	3.5025	2.9500
EV EPCOM	2009	2.5925	2.9425	0.8475	0.9625	2.7350	6.2275	5.9725	7.3175	-2.3325	-4.8025	0.5725	0.2475
EV EPCOM	2010	-1.9650	-1.1675	1.1800	2.1450	3.2725	3.7850	1.9950	7.2150	-2.3275	5.0225	3.1600	1.8475
EV EPCOM	2011	0.2550	1.1825	4.5200	5.1525	3.3250	7.9950	8.6325	9.3925	6.8950	1.6850	2.1475	-1.9000
EV EPCOM	2012	-0.9425	-1.0700	-2.2675	4.2675	0.8000	3.9925	3.4175	5.6950	1.2750	3.0075	4.3900	1.9700

```

*** EE record was read for control point      PCOM.
*** QD record was read for control point      PCOM.
*** QA record was read for control point      PCOM.
*** Starting to read PPP and/or EEE files.
*** Finished reading Precipitation.PPP file.
*** Finished reading Evaporation.EEE file.

```

```

EP Array Created with EE Record for Control Point PCOM
Extension Period 1998-2012
Mean Evaporation Volume (acre-feet/month) =    4155127.8
Mean Precipitation Volume (acre-feet/mon) =    2279870.2
Mean of EP Array Volumes                  =    2279871.8
Area (square miles) =    16284.020

```

PCOM	1998	2413162.0	3686792.8	3128865.5	958589.9	854957.1	1395191.5	1605312.1	2520511.0	3451589.5	6398320.5	3171129.2	2000001.0
PCOM	1999	738092.1	106332.5	2997003.0	1620298.5	3818055.8	2248243.0	2288296.2	180063.6	355311.2	1572153.9	212439.9	1386418.4
PCOM	2000	1727676.0	1802549.1	1604824.9	2096617.0	3446004.8	4190954.0	287343.0	215591.8	1632705.0	3972268.5	6469429.5	1794655.8
PCOM	2001	2734435.5	1760287.2	3732878.8	1035539.0	3329007.8	1572088.0	831204.2	4108578.0	2831630.8	2047821.8	4508504.5	2510725.5
PCOM	2002	1103597.2	1192741.4	1783843.9	1039409.4	1970477.0	3211968.0	6684722.5	778350.2	2353701.2	5194917.0	1529412.9	3540975.5
PCOM	2003	913010.2	3204904.5	1098155.1	452507.6	1368957.2	4733255.0	1562351.0	1586325.4	3449392.8	3203625.5	933820.8	464728.4
PCOM	2004	2498959.2	3125969.8	1873691.0	5007487.5	1976044.5	8369503.0	1720761.6	3938093.0	946576.8	4760523.0	7961165.0	635497.2
PCOM	2005	2131383.5	2684436.0	2292117.5	645603.1	3631800.8	986668.1	2082065.0	4043398.8	586067.2	907094.0	713169.8	171423.8
PCOM	2006	1288048.8	1204691.8	2711140.0	2640976.0	3036603.2	2271958.5	974097.9	744259.6	2346347.2	3877977.5	431404.9	2009910.0
PCOM	2007	4193265.5	354814.3	7216695.5	1778180.9	7926524.0	7786145.5	5101643.0	1699619.2	2847801.0	1111588.5	1532802.6	818194.9
PCOM	2008	638650.0	494854.7	2807892.5	2787956.0	2633433.8	924926.8	1002310.9	2901781.2	723444.4	2114408.0	377654.6	371219.8
PCOM	2009	564535.4	783432.9	3511022.2	4060234.2	1927350.8	1441152.0	2007890.0	1171998.1	6186272.0	7450403.0	1885488.2	1469379.9
PCOM	2010	3389906.5	2596916.8	2549826.8	2005311.6	1512194.1	2431569.0	3654321.0	457481.1	6545248.5	290219.7	579588.0	900474.0
PCOM	2011	2024617.2	834661.8	99965.6	649759.4	2278561.8	764398.8	106490.5	177226.7	852950.2	2921885.5	1443370.5	3115242.2
PCOM	2012	3124571.0	3042363.2	4804886.0	439525.7	3400065.8	1837593.5	2439134.5	1479678.6	3895299.8	673303.4	85004.0	435724.4

```

*** Finished hydrologic period-of-analysis extension routine.
*** Starting to write IN and/or EV records.
*** Finished writing IN and/or EV records.

```

```

Date:                07/30/2013
Beginning Time:      15:41:28
Ending Time:         15:41:29

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***** Normal Completion of Program WRAP-HYD *****

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## CHAPTER 6

### HYDROLOGIC REGRESSION MODEL FOR NATURALIZED FLOW EXTENSION

Chapter 6 describes a strategy added to *HYD* during 2011-2013 for extending naturalized stream flows based on Texas Water Development Board (TWDB) precipitation and evaporation datasets (Chapter 2). Companion features for extending sequences of evaporation-precipitation rates using the TWDB datasets are described in the preceding Chapter 5. Input records are described in Chapter 8 for the *HYD* features presented in Chapters 5 and 6. The Brazos WAM [12, 13] served as an inaugural case study demonstrating and testing the procedures presented in Chapters 5, 6, and 8 for extending *SIM* hydrologic periods-of-analysis.

The original sequences of naturalized flows developed during 1998-2001 for the TCEQ WAM System are based on adjusting gaged observed flows at about 500 gaging stations to remove the effects of reservoirs, water supply diversions, return flows from surface and groundwater sources, and other aspects of water resources development and use. The capabilities for developing and updating naturalized flow sequences presented in Chapters 2 and 3 are based on adjusting gaged flows. Complications associated with developing naturalized flows based on adjusting gaged flows include difficulties in compiling the water management data upon which the adjustments are based and the discontinuation of a significant number of stream gaging stations. The process of transforming actual measured flows to naturalized flows is further complicated by channel losses and travel times between stream flow sites and the locations of dam, diversion, and return flow sites which may be many miles upstream. Changes in watershed land use and long-term climate further add to the complexity.

The alternative methodology outlined here in Chapter 6 relates naturalized flows developed in the past to concurrent precipitation and evaporation. In updating existing datasets, the approach presented in Chapter 6 is much easier to implement than adjusting gaged flows. It is particularly advantageous in situations where accurate data required to adjust observed flows are unavailable or difficult to compile or stream gaging stations have been discontinued.

This new approach also provides the advantage of allowing flows to be easily updated each year. Upon completion of the *HYD* input files (hydrologic model) required to extend the period-of-analysis for a WAM dataset, the *SIM* hydrology input files can be easily updated each year after the TWDB updates the precipitation and evaporation datasets. For example, several of the WAM datasets have a hydrologic period-of-analysis of 1940-1997. The *HYD* datasets for extending the naturalized flows and reservoir surface net evaporation-precipitation rates can be created based on the existing WAM datasets that include the 1940-1997 naturalized flows and the TWDB datasets with the corresponding 1940-1997 precipitation and evaporation rates. Upon completion of a calibrated *HYD* hydrologic model (dataset), the *SIM* period-of-analysis can be extended during 2013 to cover 1940-2012 using the 1998-2012 precipitation and evaporation rates from the TWDB datasets. During 2014, when the TWDB updates the precipitation and evaporation datasets to include 2013, the same *HYD* hydrologic model based on the original 1940-1997 hydrology can be applied again to update the *SIM* hydrology files to include 2014.

The new capabilities outlined here are motivated by the need to periodically update the hydrologic periods-of-analysis of the WAM System WRAP input data files to near the present.

However, the procedures can also be applied to extend the hydrologic sequences to preceding years dating back to 1940. For example, a 1948-1998 hydrologic-period-of-analysis can be extended to 1940-2018, which includes extensions covering 1940-1947 as well as 1999-2018.

### **Organization of Naturalized Flow Extension Methodology**

Watershed and quadrangle areas are required for *HYD* to convert monthly precipitation and evaporation depths in inches to monthly volumes in acre-feet. The watershed above stream sites for which flows are synthesized may range from a portion of a single precipitation-evaporation quadrangle to all or portions of multiple quadrangles. Those quadrangles located partially or completely within the watershed of a control point are used to extend naturalized flows at that control point. For large watersheds, the quadrangles covering upper portions of the watershed that contribute little to flow at the control point may be omitted.

The *FE* record and its auxiliary supporting records are used for the extension of sequences of naturalized flows in two steps.

1. Determination of values for the parameters of the flow model based on monthly flows, precipitation, and evaporation covering the original period-of-analysis.
2. Application the flow model to synthesize flows for the extension period.

The second step is much simpler than the first. The *EE* record controls the companion task of extending the net evaporation-precipitation rates which is much simpler than extending the flows. The overall process of extending a hydrologic period-of-analysis is outlined as follows.

- Naturalized flows are extended for the primary control points. Extending naturalized flows for a particular control point involves the following tasks.

Quadrangles are identified and the areas of each quadrangle encompassed within the watershed are estimated and recorded on *QD* and *QA* records.

Parameters for the flow model are calibrated in multiple stages. The calibration process controlled by *FE* and *FP* records results in parameter values which are recorded on *UB*, *BM*, *B1*, *B2*, *B3*, *B4*, *BX*, *XP*, *X1*, *X2*, *X3*, *X4*, and *FX* records.

Flows are extended by an execution of *HYD* controlled by the *FE* record with the model parameters provided as input of the previously created *UB*, *BM*, *B1*, *B2*, *B3*, *B4*, *BX*, *XP*, *X1*, *X2*, *X3*, *X4*, *FZ*, *FR*, and *FX* records.

- The extension of reservoir surface evaporation-precipitation rates using *EE*, *QD*, and *QA* records is separate and independent of the flow extension though both extensions are based on the same TWDB precipitation and evaporation datasets. Monthly net reservoir evaporation less precipitation depths are compiled for relevant quadrangles. A weighted-average depth for adjacent quadrangles may be computed.

Calibration of the flow extension model is the most complex aspect of this process of extending a hydrologic period-of-analysis. Most of this report is devoted to explaining the calibration methodology. Again using the 1940-1997 period-of-analysis as an example, calibration consists of developing values for a set of model parameters that result in a series of

1940-1997 monthly computed naturalized flows  $Q_C(t)$  that reproduce the 1940-1997 known naturalized flows  $Q_K(t)$  as closely as possible. Upon completion of the calibration process, the calibrated model is applied to compute 1998-2012 monthly flows  $Q(t)$  based on 1998-2012 sequences of monthly precipitation and evaporation observations.

The objective of the flow extension process is to properly reproduce the statistical characteristics of the naturalized flows. The synthesized flow in each individual month is necessarily approximate. However, a computed flow in one month that is a little high will be balanced by a flow that is a little low in another month. The procedure is designed to develop flow sequences with the correct means, standard deviations, and flow-frequency relationships.

The calibration process consists of two sequential levels of computational methods. The various user-selected options associated with the multiple stages of the two levels are described in this report along with explanations of computational methods.

1. Level 1 consists of automated enumeration and gradient search optimization algorithms that calibrate parameters  $U(1)$ ,  $U(2)$ ,  $B(m)$ ,  $BX(z)$ ,  $X(i,j,z)$ , and  $DX$  of the flow model (Eqs. 1-5) based on known naturalized flows  $Q_K(t)$  for each month  $t$  of the original period-of-analysis and corresponding precipitation and evaporation rates. The resulting values for these parameters are recorded on *HYD* extension input records. The resulting flow synthesis model is applied to compute flows  $Q_C(t)$  for each month of the original period-of-analysis for use in level 2. The automated optimization based parameter calibration procedure consists of the following sequential steps that are performed within a single execution of *HYD*.
  - a. An enumeration algorithm is applied to develop initial estimates of the values of the parameters. An objective function is evaluated for numerous combinations of parameter values to find the values that minimize the objective function.
  - b. A univariate gradient search optimization algorithm starts with the initial estimates and further adjusts the parameters to find values that minimize an objective function.
  - c. A final set of enumeration-based optimization algorithms check and refine the optimal values of  $U(1)$ ,  $U(2)$ ,  $B(m)$ ,  $BX(z)$ ,  $X(i,j,z)$ , and  $DX$ .
2. Level 2 is based on analyzing the period-of-analysis flows  $Q_C(t)$  computed in the first level described above and adjusting the model to better reproduce the statistical characteristics of the  $Q_K(t)$ . Additional parameters are adopted for the following level 2 flow adjustments.
  - a. The  $Q_C(t)$  and  $Q_K(t)$  are each divided into 12 ranges representing flow frequency relationships. The ratios  $FX(r)$  of the mean  $Q_K(t)$  to mean  $Q_C(t)$  for each range are recorded on *FX* records and incorporated in the model as multiplier factors to force the model to more closely reproduce the statistical characteristics of the  $Q_K(t)$ .
  - b. *HYD* also includes an optional feature for performing linear and/or nonlinear regression of  $Q_K(t)$  versus  $Q_C(t)$ .
  - c. The final option is designed to improve model accuracy in generating zero and near-zero flows. Two parameters  $ZF(1)$  and  $ZF(2)$  are developed and recorded on the *UB* record based on comparing zero and near-zero computed and known flows.

### Low, Medium, High, and Flood Flows

Low, medium, high, and flood flow zones are defined by the parameters LU, ML, MU, HL, HU, and FL, in acre-feet/month, entered on the flow zone *FZ* record. These limits are designed to be set based on *TABLES 2FRE* frequency tables that relate naturalized stream flow quantities to specified exceedance frequencies. The zone demarcations are defined as follows.

FL    lower limit of the flood flow zone  
 HU    upper limit of the high flow zone  
 HL    lower limit of the high flow zone  
 MU    upper limit of the medium flow zone  
 ML    lower limit of the medium flow zone  
 LU    upper limit of the low flow zone

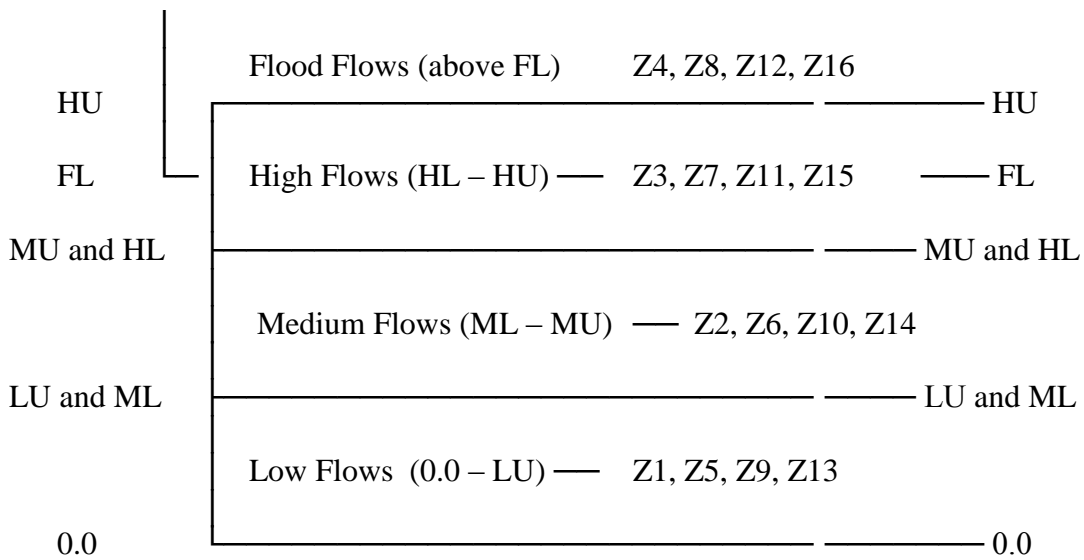


Figure 6.1 Flow Zones for the *FZ* Record FE(13) Default Option 1

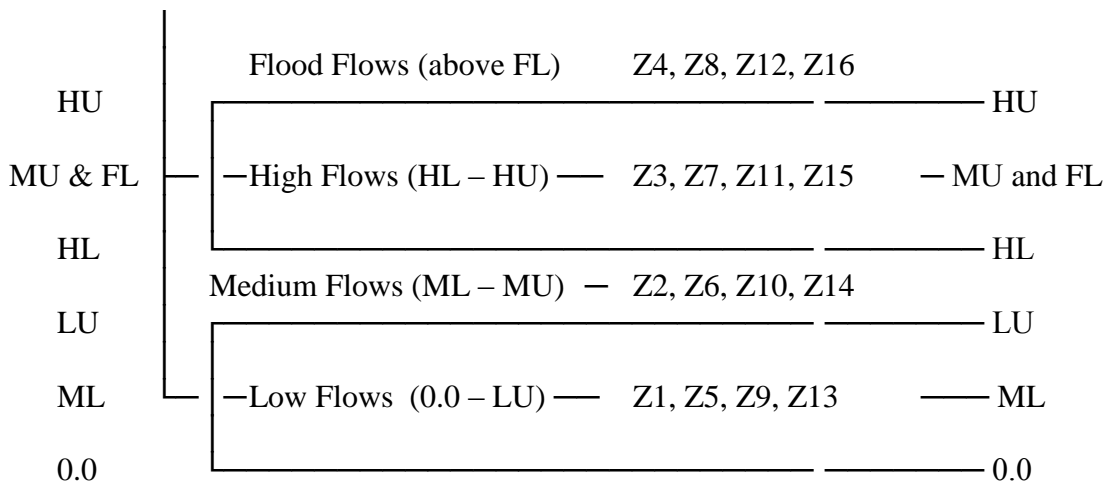


Figure 6.2 Flow Zones for *FZ* Record FE(13) Option 2

The optional flow zones are delineated on the *ZR* record. With no *ZR* record, flow is not divided into zones. Figures 6.1 and 6.2 illustrate two variations of options for defining flow zones on the *ZR* record. The first option shown in Figure 6.1 has overlapping flood flow and high flow zones. However, the overlap can be removed by entering the same value for *HU* and *FL*. The option shown in Figure 6.2 includes overlaps between each pair of adjacent zones. However, any of the overlaps can be removed by assigning the same value to two limits.

The limits *ML*, *LU*, *HL*, *MU*, *FL*, and *HU* defining the demarcation between flow zones are entered on the *ZR* record in units of acre-feet/month. These limits are designed to be selected based on *TABLES 2FRE* frequency tables that relate naturalized stream flow volumes to exceedance frequencies. For example, *LU/ML*, *MU/HL*, *FL*, and *HU* in Figure 6.1 could be assigned the monthly naturalized flow volumes from a WAM dataset with exceedance frequencies of 80%, 60%, 40%, and 30%. With the overlapping flow zones shown in Figure 6.2, *ML*, *LU*, *HL*, *MU/FL*, and *HU* could be set as the known monthly naturalized flow volumes from a WAM dataset that have exceedance frequencies of 80%, 60%, 40%, 20%, and 10%.

Flows are categorized as occurring within zones for two related but distinctly different aspects of the flow extension computations.

1. The flow model presented as Equations 1, 2, 3, 4, and 5 in the next section can be applied separately for different flow zones (*z*). Separate sets of values for the parameters *B(m,z)*, *DX(z)*, and *X(i,j,z)* are calibrated and applied separately for low flows, medium flows, high flows, and flood flows or various groupings thereof.
2. The criteria metrics (*Zs* defined by Eqs. 9, 10, 11, and 12) used in the parameter calibration algorithms can be formulated separately for different flow zones. The calibration can be based on minimizing various measures of the differences between known and computed flows in the alternative flow zones.

### **Naturalized Stream Flow Equation**

The flow model (Equations 1, 2, 3, 4, 5) upon which the flow extension methodology is based is calibrated using naturalized monthly flows from a WAM dataset covering the period-of-analysis and the corresponding monthly precipitation and evaporation sequences from the TWDB datasets for the same period-of-analysis. Upon completion of the calibration process, flows are synthesized for the period-of-extension by applying the calibrated flow model with precipitation and evaporation sequences from the TWDB datasets for the period-of-extension.

Although the evaporation extension *EE* record works directly with the observed monthly evaporation depths in inches, the flow extension *FE* record computations deal with precipitation and evaporation volumes *P(i,t)* and *E(i,t)* in units of acre-feet/month. Depths for each relevant month (*t*) and quadrangle (*i*) are read by *HYD* from the two files of precipitation and evaporation depths with filenames *Precipitation.PPP* and *Evaporation.EEE*. The depths (rates) in inches/month are transformed within *HYD* to volumes *P(i,t)* and *E(i,t)* in acre-feet/month.

$$P(i,t) = (\text{precipitation depth})(\text{area of quadrangle } i \text{ within watershed})(\text{units conversion factor})$$

$$E(i,t) = (\text{evaporation depth})(\text{area of quadrangle } i \text{ within watershed})(\text{units conversion factor})$$

Monthly naturalized flow volumes  $Q(t)$  at a control point location are synthesized with the combined Eqs. 1, 2, 3, 4, and 5.  $Q(t)$ ,  $RP(t)$ ,  $BF(t)$  and other variables are constrained to be non-negative. As discussed in the preceding section, flows may optionally be divided into zones ( $z$ ) representing low, medium, high, and flood flows. A single flow model may be developed for all flows or separate models be developed for specified zones or some specified combination of zones. If flow zones are delineated, the flow  $Q(t)$  for month  $t$  is either assigned  $Q(t,z)$  for the appropriate flow zone or computed as a weighted average of  $Q(t,z)$  for overlapping zones.

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

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

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

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

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

- $Q(t)$  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 ( $0.0 \leq U(1) \leq 1.0$  and  $0.7 \geq U(2)$ )
- $N$  number of quadrangles included in the watershed ( $i = 1, 2, 3, \dots, N$ )
- $P(i,t)$  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 ( $m = 1, 2, 3, \dots, 12$ ) 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
- $\bar{P}(m)$  monthly means of precipitation volumes for each of the  $m = 1, 2, 3, \dots, 12$  months of the year for specified quadrangles (acre-feet/month)
- $\bar{E}(m)$  monthly means of evaporation volumes for each of the  $m = 1, 2, 3, \dots, 12$  months of the year for specified quadrangles (acre-feet/month)

The flow model contains the following  $4(13+5N)+3$  parameters which are calibrated using naturalized flows from the TCEQ WAM System and precipitation and evaporation from the TWDB datasets. The index  $z$  refers to four flow zones (low, medium, high, flood). Other parameters are provided as model input without being automatically calibrated.

- $B(m,z)$  base flow (ac-ft/month) for each month of the year ( $m = 1$  to 12 and  $z = 1$  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  $0.0 \leq U(1) \leq 1.0$  and  $0.7 \geq U(2)$ .

The flow equation (Eqs. 1,2,3,4,5) is essentially a form of regression equation with the time series of flows  $Q(t)$  regressed as a function of the  $N$  time series of monthly precipitation  $P(i,t)$  and evaporation  $E(i,t)$ . The coefficients  $U(1)$ ,  $U(2)$ ,  $X(i,j,z)$ ,  $B(m,z)$ ,  $BX(z)$ , and  $DX$  are determined based on known sequences of  $P(i,t)$ ,  $E(i,t)$ , and  $Q(t)$ . However, the flow equation is structured in a format that is representative of actual hydrologic processes. The terms are related to physical concepts.  $B(m,z) \times DX(z)$  represents base flows for each of the 12 months of the year in acre-feet/month that can be adjusted by a dimensionless drought index that reflects long-term hydrology.  $U(k)$  and  $X(i,j,z)$  are precipitation-runoff parameters.  $X(i,j,z)$  model runoff from each of the  $N$  individual quadrangles encompassed by the watershed above the control point location of the flows  $Q(t)$ .  $U(1)$  and  $U(2)$  model the nonlinear response of total flow to rainfall.

The basic watershed volume budget is expressed as Eq. 6 below, where  $Q_T$ ,  $B_T$ ,  $P_T$ ,  $P_{T-1}$ ,  $L_T$ ,  $L_{T-1}$ , and  $E_T$  represent volumes of stream flow, base flow, precipitation, total losses, and maximum potential evapotranspiration during the current month  $t$  and preceding month  $t-1$ , and  $a$ ,  $b$ , and  $c$  are coefficients. Precipitation occurring in both the current and preceding months contributes to the volume flowing past the watershed outlet during the current month.

$$\text{stream flow} = \text{base flow} + \text{precipitation} - \text{losses}$$

$$Q_T = B_T + P_T - L_T + (P_{T-1} - L_{T-1}) \quad \text{where} \quad L = aP^b + cE \quad (6)$$

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 shown in Eq. 6 as a function of precipitation  $P$  and evaporation  $E$ . Hydrologic

abstractions are viewed partially, but only partially, as a function of reservoir surface evaporation rates which represent a maximum potential evapotranspiration rate from a watershed.

The flow equation (Eq. 1) with its component Eqs. 2, 3, 4, and 5 visualize flows  $Q(t)$  conceptually as the summation of base flows  $BF(t)$ , flows from rainfall  $P(i,t)$  occurring in the same month  $t$  as the resulting flow  $Q(t)$  at the watershed outlet, and contributions to flow from rainfall  $PP(i,t-1)$  in the preceding month less losses in the preceding and current months.

$P(i,t)$  denotes volumes of precipitation falling on each portion of the watershed (quadrangle  $i$ ) during the same current month as  $Q(t)$ . Precipitation falling in the preceding month  $t-1$  may also contribute to  $Q(t)$ .  $PP(t) = X(i,1)P(i,t)^{X(i,j)}$  represents the portion of  $P(i,t)$  that does not contribute to stream flow in month  $t$  but may contribute to flow in the next month.  $PP(i,t)$  contributes to  $Q(t+1)$  in the following month  $t+1$  and/or is lost as hydrologic abstractions. The  $PP(t)$  computed in month  $t$  becomes a source of water available in the following month  $t+1$ .

Reservoir water surface evaporation rates approximate the potential evapotranspiration capacity rates for the hypothetical condition of a completely saturated ground surface throughout a watershed. Hydrologic abstractions (losses) are modeled in the flow equation partially as a function of  $E(i,t)$  which is the maximum evapotranspiration potential represented as reservoir evaporation rates applied over the total watershed land area. Losses are modeled as functions of  $P(i,t)$ ,  $PP(i,t)$ , and  $E(i,t)$ .

$$\text{Losses} = X(i,1) \times P(i,t)^{X(i,2)} + X(i,3) \times E(i,t) + X(i,4) \times PP(i,t)^{X(i,5)} \quad (7)$$

Base flows  $BF(t)$  from subsurface hydrologic processes that respond slowly to precipitation may contribute to stream flow and maintain low flows during long periods of little or no precipitation. The  $BF(t)$  component of  $Q(t)$  may originate from precipitation occurring before and/or during the current and preceding months, including precipitation occurring many months or years before. *HYD* provides various options that are combined to model base flows.

The base flow calibration parameters  $B(m,z)$  and  $BX(z)$  may differ for different zones or may be the same for all zones. The  $B(m) \times BX$  may vary seasonally over the 12 months of the year and may be zero in some or all months at some stream sites. The 12  $B(m)$  for the 12 months of the year may be set at fixed values or included in the automated parameter calibration. Likewise,  $BX$  may be fixed at a specified value or treated as a calibration parameter in the automated calibration procedure. The default for  $BX$  is 1.0. *HYD* includes a default routine that computes the values of the 12  $B(m)$  as the mean of the smallest six naturalized flows in the WAM dataset for each month of the year.  $B(1)$  is the mean of the smallest six January flows,  $B(2)$  is the mean of the smallest six February flows, and so forth. These averages reflect the seasonality of low flows. These 12  $B(m)$  can be fixed with  $BX$  treated as a calibration parameter. Alternatively, the 12 means can be treated as upper limits or initial estimates for  $B(m)$  subject to further adjustments in the automated optimization-based calibration procedure.

### **Drought Index**

The base flow component  $BF(t,z)$  (Eq. 4) of the flow equation includes a drought index  $DI(t)$  term (Eq.5). The  $DI(t)$  allows the base flow  $BF(t,z)$  to decrease below  $B(m,z) \times BX(z)$

during dry periods. The  $DI(t)$  reduces the base flow  $BF(t,z)$  during months that are drier than normal but has no effect on the  $BF(t,z)$  during months that are wetter than normal. The dimensionless drought index  $DI(t)$  for any month  $t$  is constrained to range between 0.0 and 1.0.

$$BF(t,z) = B(m,z) \times DI(t) \times BX(z) \quad (4)$$

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

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

$E(i,t)$  evaporation volume in acre-feet/month during the month  $t$  in quadrangle  $i$

$\bar{P}(m)$  monthly averages of precipitation volumes in acre-feet/month for each of the 12 months of the year ( $m = 1, 2, 3, \dots, 12$  denoting January through December) covering the selected quadrangles specified on the *QD* record

$\bar{E}(m)$  monthly means of evaporation volumes in acre-feet/month for January, February, March, ..., December covering the quadrangles specified on the *QD* record

$DX$  dimensionless non-negative multiplier factor with a default of 1.0

The quadrangles used in the flow extension computations are listed on the *QD* record. Normally all of the quadrangles covering the entire watershed will be included on the *QD* record. By default, the drought index uses all of the quadrangles listed on the *QD* record. However, a *QD* record option allows a selected subset of the quadrangles to be applied in computing the drought index while all of the quadrangles are used in all of the other computations.

The drought index is based on the ratio of two-month precipitation volume to two-month evaporation volume occurring during the current and preceding months ( $t$  and  $t-1$ ) summed over selected quadrangles expressed as a ratio of the corresponding long-term period-of-analysis means of the precipitation/evaporation ratio for these two months of the calendar year. Approximately normal or average hydrologic conditions are represented by a  $DI(t)$  of 1.0. Thus,  $DI(t)$  at its upper limit of 1.0 indicates either average or wetter than average conditions than are normal for that season of the year. A  $DI(t)$  of significantly less than 1.0 indicates drier than average conditions than normal for that season. A  $DI(t)$  of 0.0 indicates that zero precipitation occurred during the current and preceding months. The  $DI(t)$  affects flows only during months that are drier than normal, with the effects being greater during very dry periods. Optionally, the  $DI(t)$  may be fixed at 1.0 and thus deactivated.

The drought index  $DI(t)$  is constrained to vary only between 1.0 and 0.0, but the multiplier factor  $DX$  can significantly affect the variation of  $DI(t)$  between 1.0 and 0.0. A computed  $DI(t)$  of greater than 1.0 in a particular month is set at 1.0. The parameter  $DX$  defaults to 1.0, but any value for  $DX$  can be calibrated and applied. There is only one  $DX$ .  $DX$  does not vary with flow range or between months.

## **Combining Component Models for Alternative Flow Zones**

The user-specified quantities LU, ML, MU, HL, HU, and FL entered on the *FZ* record define the demarcation between low, medium, high, and flood flows for the purposes of both (1) establishing values the parameters  $B(m,z)$ ,  $BX(z)$ , and  $X(i,j,z)$  through the parameter calibration process and (2) applying the resulting four different sets of values of the parameters to extend the flows. Known flows are available for the period-of-analysis for use in the parameter calibration computations. The flow limits are referenced to known flows for computing the criterion metrics (defined later) in the parameter calibration process. Known flows are not available for the period-of-extension. After completion of parameter calibration, flows  $Q(t)$  are computed with Equation 1 for the period-of-extension based on defined rules which are described as follows. Since naturalized flows are not yet known for the extension period, the flow limits of necessity are referenced to computed flows in applying the rules to synthesize flows.

A single set of parameter values reflecting a single model may be applied to all flows. In this case, low, medium, high, and flood flow zones may still be delineated for purposes of applying the optimization criteria metrics described in the next section even though the calibration results in a single set of parameter values. There is no need to overlap flow zones if the only purpose of the flow zones is the formulation of the criteria metrics used in calibration.

Flows may possibly be modeled more accurately by developing separate models for low, medium, high, and flood flows. However, the combining of the separate component models is a significant concern and a distinct disadvantage of this modeling option. The sole purpose of overlapping flow zones is to facilitate the adoption of separate models for low, medium, high, and flood flows. In general, *HYD* flow extension capabilities are designed for two alternative optional strategies for developing separate models for different levels of flow.

1. The alternative strategy illustrated by Figure 6.1 consists of adopting two models, one for flood flows and another for all other flows. The two models are combined following the rules outlined in Table 6.1.
2. The other alternative strategy illustrated by Figure 6.2 consists of adopting four separate models for low, medium, high, and flood flows. The four models are combined following the rules outlined in Table 6.2.

For the flow extension strategy with the zones shown in Figure 6.1 and rules outlined in Table 6.1, flows are synthesized for the period-of-extension using the flow equation (Eqs. 1, 2, 3, 4, 5) with the two sets of parameters  $B(m,z)$ ,  $BX(z)$ , and  $X(i,j,z)$  provided as input on *BM*, *B4*, *XM*, *X4*, and *UB* records previously generated by the calibration process. For each month, *HYD* computes values of  $Q(t,z)$  with the two alternative sets of parameters yielding  $Q(t)_X$  and  $Q(t)_F$ .

For the flow extension strategy with the zones shown in Figure 6.2 and rules outlined in Table 6.2, flows are synthesized with the four sets of parameters  $B(m,z)$ ,  $BX(z)$ , and  $X(i,j,z)$  for low, medium, high, and flood flows provided as input on *B1*, *B2*, *B3*, *B4*, *X1*, *X2*, *X3*, *X4*, and *UB* records previously generated by the calibration process. For each month, *HYD* computes values of  $Q(t,z)$  with the four alternative sets of parameters yielding  $Q(t)_L$ ,  $Q(t)_M$ ,  $Q(t)_H$  and  $Q(t)_F$ . The final  $Q(t)$  is adopted as outlined in Table 6.1 based on 14 possibilities for flow occurring in the ranges shown in Figure 6.2.

Table 6.1  
Rules for Determining  $Q(t)$  based on  $Q(t)_X$  and  $Q(t)_F$  Illustrated by Figure 6.1

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If $Q(t)_X \leq FL$	and $Q(t)_F \leq FL$	then $Q(t) = Q(t)_X$
If $Q(t)_X \geq HU$	and $Q(t)_F \geq HU$	then $Q(t) = Q(t)_F$
If $Q(t)_X \leq FL$	and $Q(t)_F \leq FL$	and $Q(t)_F \leq HU$
		then $Q(t) = Q(t)_F[(Q(t)_F - FL)/(Q(t)_F - Q(t)_X)] + Q(t)_X[(FL - Q(t)_X)/(Q(t)_F - Q(t)_X)]$
If $Q(t)_X < HU$	and $Q(t)_F > HU$	then $Q(t) = Q(t)_F[(Q(t)_F - HU)/(Q(t)_F - Q(t)_X)] + Q(t)_X[(HU - Q(t)_X)/(Q(t)_F - Q(t)_X)]$
Else		$Q(t) = (Q(t)_X + Q(t)_F)/2.0$

---

Table 6.2  
Rules for Determining  $Q(t)$  based on  $Q(t)_L$ ,  $Q(t)_M$ ,  $Q(t)_H$  and  $Q(t)_F$  Illustrated by Figure 6.2

If  $Q(t)_M \leq HL$  and

1. If  $Q(t)_L \leq ML$  and  $Q(t)_M < LU$  then  $Q(t) = Q(t)_L$
2. If  $ML < Q(t)_M < LU$  and  $ML < Q(t)_L < LU$  then  $Q(t) = (Q(t)_M + Q(t)_L)/2.0$
3. If  $ML < Q(t)_M < LU$  and  $Q(t)_L \geq LU$  then  $Q(t) = (Q(t)_M + LU)/2.0$
4. If  $ML < Q(t)_L < LU$  and  $Q(t)_M \leq ML$  then  $Q(t) = (Q(t)_L + ML)/2.0$
5. If  $Q(t)_L \leq ML$  and  $Q(t)_M \geq LU$  then  $Q(t) = (Q(t)_L + Q(t)_M)/2.0$
6. If  $LU \leq Q(t)_M \leq HL$  and  $Q(t)_L > ML$  then  $Q(t) = Q(t)_M$

If  $Q(t)_M > HL$  and

7. If  $HL < Q(t)_M \leq MU$  and  $HL \leq Q(t)_H \leq MU$  then  $Q(t) = (Q(t)_M + Q(t)_H)/2.0$
8. If  $HL < Q(t)_M \leq MU$  and  $Q(t)_H < HL$  then  $Q(t) = (Q(t)_M + HL)/2.0$
9. If  $HL \leq Q(t)_H \leq MU$  and  $Q(t)_M > MU$  then  $Q(t) = (Q(t)_H + MU)/2.0$
10. If  $Q(t)_H < HL$  and  $Q(t)_M > MU$  then  $Q(t) = (HL + MU)/2.0$
11. If  $MU < Q(t)_H \leq HU$  and  $Q(t)_F < HU$  then  $Q(t) = (Q(t)_H + Q(t)_F)/2.0$
12. If  $MU < Q(t)_H \leq HU$  and  $Q(t)_F > HU$  then  

$$Q(t) = Q(t)_F[(Q(t)_F - HU)/(Q(t)_F - Q(t)_H)] + Q(t)_H[(HU - Q(t)_H)/(Q(t)_F - Q(t)_H)]$$
13. If  $Q(t)_F > HU$  and  $Q(t)_H \geq HU$  then  $Q(t) = Q(t)_F$
14. If  $Q(t)_F < HU$  and  $Q(t)_H > HU$  then  

$$Q(t) = Q(t)_F[(HU - Q(t)_F)/(Q(t)_H - Q(t)_F)] + Q(t)_H[(Q(t)_H - HU)/(Q(t)_H - Q(t)_F)]$$

## Objective Function Criteria Metrics for the Optimization Algorithms

The automated calibration methodology requires metrics for comparing the optimality of alternative sets of values for the decision variables (model parameters). These metrics are called criterion or objective functions. The optimization problem consists of finding values for decision variables that minimize a specified objective function defined by Eq. 8. The 16 criteria functions defined by Eqs. 9, 10, 11, and 12 are computed. The objective function OF and all 16 criterion metrics Z are recorded in the *HYD* message HMS file for information. The automated parameter calibration optimization procedure incorporates Eq. 8 as its objective function OF. Eq. 8 is a weighted summation of the criterion functions Z defined by Eqs. 9, 10, 11, and 12. Values for the 16 weighting factors W1–W16 are provided on the *FP* record.

$$\begin{array}{cccc}
 \text{low flows} & \text{medium} & \text{high} & \text{flood flows} \\
 \text{OF} = & W1 \times Z1 & + & W2 \times Z2 & + & W3 \times Z3 & + & W4 \times Z4 & + \\
 & W5 \times Z5 & + & W6 \times Z6 & + & W7 \times Z7 & + & W8 \times Z8 & + \\
 & W9 \times Z9 & + & W10 \times Z10 & + & W11 \times Z11 & + & W12 \times Z12 & + \\
 & W13 \times Z13 & + & W14 \times Z14 & + & W15 \times Z15 & + & W16 \times Z16
 \end{array} \quad (8)$$

$$Z1 = Z2 = Z3 = Z4 = \left( \frac{1}{K} \right) \sum_{t=1}^K \left( \frac{100 \times |Q(t)_{\text{known}} - Q(t)_{\text{computed}}|}{\overline{Q(t)_{\text{known}}}} \right)^{E1} \quad (9)$$

$$Z5 = Z6 = Z7 = Z8 = \left( \frac{1}{K} \right) \sum_{t=1}^K \left( \frac{100 \times |Q(t)_{\text{known}} - Q(t)_{\text{computed}}|}{ZZZ} \right)^{E1} \quad (10)$$

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

$$Z9 = Z10 = Z11 = Z12 = |N_K - N_C|^{E1} \quad (11)$$

$$Z13 = Z14 = Z15 = Z16 = \left( \frac{1}{K} \right) \frac{\left( 100 \times \left| \sum_{t=1}^K Q(t)_{\text{known}} - \sum_{t=1}^K Q(t)_{\text{computed}} \right| \right)^{E2}}{\overline{Q_{\text{known}}}} \quad (12)$$

OF	objective function applied in the automated search optimization procedure
Z1–Z16	dimensionless criteria metrics that are recorded in the message HMS file and serve as components of the objective function OF of Eq. 8.
W1–W16	dimensionless weighting factors entered on the <i>FP</i> record that may serve as 1.0 or 0.0 on/off switches or priority weights having any value
$Q(t)_{\text{known}}$	known monthly naturalized stream flows from the TCEQ WAM System dataset at the location of interest in units of acre-feet/month.

$Q(t)_{\text{computed}}$	flows in ac-ft/month computed with the flow model (Eqs. 1-5) for each month $t$ where the model parameters are optimization decision variables
$N_K$	number of months during which the known flows fall within the specified low, medium, high, or flood flow range
$N_C$	number of months during which the computed flows fall within the specified low, medium, high, or flood flow range
$\overline{Q(t)}_{\text{known}}$	mean of the known flows during the $K$ months used in computing $Z$ for either low, medium, high, flood, or all flows in acre-feet/month
$K$	number of months is either TL, TM, TH, TF, or T
$E1, E2$	exponents set on $FP$ record with defaults of 2.0 that penalize large differences between computed and known flows more than small differences

$T$  and  $NYRS$  are the total number of months and years in the period-of-analysis. For example for a 1940-1998 period-of-analysis,  $NYRS$  is 59 years and  $T$  is 708 months. The criterion metrics are based on specified flow ranges. The demarcations between low, medium, high, and flood flows are defined by the limits  $LU$ ,  $ML$ ,  $MU$ ,  $HL$ ,  $HU$ , and  $FL$  in acre-feet/month, from the  $FZ$  record, as illustrated by Figures 6.1 and 6.2. The  $T$  months are divided into the months of low (TL), medium (TM), high (TH), and flood (TF) flows where  $T \leq TL + TM + TH + TF$ . The number of months  $K$  in Eqs. 9, 10, and 12 is either TL, TM, TH, TF, or T. The criterion metric equations are applied in only those months with flows falling within ranges defined by the limits  $LU$ ,  $ML$ ,  $MU$ ,  $HL$ ,  $HU$ , and  $FL$ .

Equations 9, 10, 11, and 12 provide four types of criteria metrics, measuring different flow characteristics, applied to flows falling within four ranges, generating a total of 16 metrics.

$Z1, Z5, Z9$ , and  $Z13$  apply to low flows (0.0 to  $LU$ ).

$Z2, Z6, Z10$ , and  $Z14$  apply to medium flows ( $ML$  to  $MU$ ).

$Z3, Z7, Z11$ , and  $Z15$  apply to high flows. ( $HL$  to  $HU$ ).

$Z4, Z8, Z12$ , and  $Z16$  apply to flood flows. (above  $FL$ ).

$Z1, Z2, Z3$ , and  $Z4$  computed with Eq. 9 are identical except for the TL, TM, TH, or TF months included in the summation of the absolute value of the differences between known and computed flows. Likewise,  $Z5, Z6, Z7$ , and  $Z8$  computed with Eq. 10 are identical except for the selection of months to be included in the summation.  $Z9, Z10, Z11$ , and  $Z12$  computed with Eq. 11 and  $Z13, Z14, Z15$ , and  $Z16$  computed with Eq. 12 likewise include TL low (0.0 to  $LU$ ), TM medium ( $ML$  to  $MU$ ), TH high ( $HL$  to  $HU$ ) or TF flood (above  $MU$ ) flow months, respectively.

The objective function  $OF$  and criteria metrics  $Z$  of Eqs. 8, 9, 10, 11, and 12 are dimensionless. Differences between computed and known flow volumes in acre-feet/month are divided by a flow volume in acre-feet/month. Differences between computed and known flows as dimensionless fractions are multiplied by 100% and raised to a power (default=2.0) which penalizes large differences more than small differences. The primary purpose for formulating the metrics as similar dimensionless quantities is to facilitate combining the metrics in the objective function. Any or all of the criterion metrics may be selected for inclusion in the same objective function.

The objective function (OF) adopted for the optimization procedure is computed with Equation 8. The dimensionless OF is a weighted summation of Zs computed with Eqs. 9, 10, 11 and 12. The dimensionless weighting factors W1, W2, W3, W4, W5, W6, W7, W8, W9, W10, W11, W12, W13, W14, W15, and W16 are specified on the *FP* record. The weighting factors may be 0.0 or 1.0 switches or a mechanism for balancing the components of the OF. The optimization procedure consists of finding values for the parameters (decision variables) U(1), U(2), B(m), BX, DX, and X(i,j) that result in the objective function OF being as small (close to zero) as possible. The metrics Z1, Z2, Z3, Z4, Z5, Z6, Z7, Z8, Z9, Z10, Z11, Z12, Z13, Z14, Z15, and Z16 and the adopted OF are all included in the *HYD* message HMS output file.

Either Z1, Z2, Z3, Z4, Z5, Z6, Z7, Z8, Z9, Z10, Z11, Z12, Z13, Z14, Z15, or Z16 or any linearly weighted summation of combinations thereof can be adopted as the objective function OF in the automated optimization procedure by selection of entries in the *FP* record for the factors W1, W2, W3, W4, W5, W6, W7, W8, W9, W10, W11, W12, W13, W14, W15, and W16 of Eq. 8. A Z1, Z2, Z3, and Z4 of exactly zero computed by *HYD* would indicate a perfect fit of computed flows to known flows with the other Z metrics being zero as well. However, since zero deviations in all months is essentially impossible with actual data, the alternative Z metrics provide a mechanism for weighting tradeoffs between the various flow characteristics that are best reproduced by the selected values of the parameters U(1), U(2), B(m), DX, and X(i,j).

Z1, Z2, Z3, and Z4 defined by Eq. 9 focus on deviations between known and computed flows in each of the individual months. These criterion metrics reflect the absolute values of the differences between known flows from a WAM dataset and the corresponding flows computed within *HYD* with Eq. 1 expressed as a dimensionless percentage of the average of the known flows for the same TL, TM, TH, TF, or T months. The flow differences are divided by the period-of-analysis mean of the known flows for the low, medium, high, and flood flow ranges. Thus, the flow differences are expressed as percentages of the mean of the TL, TM, TH, or TF known flows. If flow limits are not specified, the mean is for the T known flows. The percent differences are raised to the exponent E1 (default = 2) which weights a large difference more than a smaller difference between computed and known flows for a given known flow.

Differences between known and observed flows for larger flows tend to be larger than differences between smaller flows. Thus, minimizing Z1, Z2, Z3, and Z4 tends to emphasize the larger flows within each of the four flow ranges. Z5, Z6, Z7, and Z8 are designed to increase the emphasis on lower flows in the calibration process.

Z5, Z6, Z7, and Z8 computed with Eq. 9 are based on the absolute values of deviations between known flows from a WAM dataset and the corresponding flows computed within *HYD* with Eq. 1, expressed as a percentage of the either the known or computed flow. The divisor ZZZ is set as the larger of the known or computed flow, which prevents dividing by zero or extremely small numbers. Differences are considered only for flows of at least 1.0 ac-ft/month.

Alternative criterion metrics Z9, Z10, Z11, and Z12 computed with Eq. 11 are based on counting the number of months of the period-of-analysis during which the known and computed flows fall within the specified flow range. The objective is to minimize the deviation between the number of months of computed and known flows in specified flow zones.

Z13, Z14, Z15, and Z16 defined by Eq. 12 are based on the differences between the mean of the known flows from the WAM System dataset and the mean of the flows computed with Eq. 1 divided by the mean of the known flows from the WAM System dataset. Values for Z13, Z14, Z15, and Z16 of exactly zero indicate that the flow equation (Eq. 1) with specified parameter values perfectly reproduces the long-term period-of-analysis mean and thus total volume of the known flows. Z13, Z14, Z15, and Z16 include either the TL months of low flows, TM months of medium flows, TH months of high flows, or TF months of flood flows, respectively.

Variations of the following objective functions may be adopted in calibrating parameters for low, medium, high, and flood flows.

low flows	$OF = 1.0 \times Z1 + 1.0 \times Z5 + 1.0 \times Z9 + 1.0 \times Z13$
medium flows	$OF = 1.0 \times Z2 + 1.0 \times Z6 + 1.0 \times Z10 + 1.0 \times Z14$
high flows	$OF = 1.0 \times Z3 + 1.0 \times Z7 + 1.0 \times Z11 + 1.0 \times Z15$
flood flows	$OF = 1.0 \times Z4 + 1.0 \times Z8 + 1.0 \times Z12 + 1.0 \times Z16$

A W of 0.0 removes a Z from consideration. Numbers other than 1.0 may be assigned on the *FP* record for the W weighting factors to vary the influence of each of the Z criterion metrics on the parameter calibration. The alternative Z's allow different characteristics of the flows to be considered, realizing that the monthly volumes cannot be reproduced exactly in each and every month. For example, Z13, Z14, Z15, and Z16 focus on finding a set of parameter values that replicate the period-of-analysis means of the known low, medium, high, and flood flows.

### **Univariate Gradient Search Optimization Technique**

The automated *FE/FP* record parameter calibration procedure of the WRAP program *HYD* uses optimization algorithms that search for the set of values for decision variables that minimize a specified objective function. The gradient search algorithm is a key component of the overall parameter calibration strategy. The univariate gradient search technique is covered in the published literature [14, 15] and is described below prior to outlining the overall parameter calibration methodology incorporated in *HYD*.

The univariate gradient search optimization procedure is a cyclic algorithm that optimizes one variable at a time while the other variables are temporarily held constant. The computations are repeated iteratively to adjust each individual variable in turn. A cycle consists of finding an improved value for each of the decision variables. The cyclic search begins with an initial estimate of decision variable values and continues until specified stop criteria are met.

1. Initial values are estimated for all of the decision variables.
2. One decision variable is improved using the Newton-Raphson method while all other decision variables are held constant at their current values.
3. Step 2 is repeated for the next decision variable in turn until the cycle is completed in which all decision variables are adjusted.
4. The stop criteria are checked. If the stop criteria are not satisfied, another cycle is performed by repeating steps 2 and 3 above.

For each univariate search iteration (step 2 above), the Newton-Raphson formula (Eq. 13) is applied to determine an improved value  $x^*$  given the current value of  $x$  and the first and second derivatives  $f'(x)$  and  $f''(x)$  of the objective function  $f(x)$ .

$$x^* = x - \frac{f'(x)}{f''(x)} \quad (13)$$

The first and second derivatives  $f'(x)$  and  $f''(x)$  are approximated with the following finite-difference formulas (Eqs. 14 and 15).

$$f'(x) = \frac{f(x+\Delta x) - f(x-\Delta x)}{2\Delta x} \quad (14)$$

$$f''(x) = \frac{f(x+\Delta x) - 2f(x) + f(x-\Delta x)}{\Delta x^2} \quad (15)$$

The objective function  $OF=f(x)$  is expressed by Eq. 8 in the *FE/FP* record automated parameter calibration procedure.  $Q(t)_{\text{computed}}$  are computed with Eq. 1.  $B(m)$ ,  $BX$ ,  $X(i,j)$ ,  $U(1)$ , and  $U(2)$  are the decision variables ( $x$ ) that are iteratively adjusted using Eq. 13. The objective function  $OF$  is computed three times [ $f(x)$ ,  $f(x+\Delta x)$ ,  $f(x-\Delta x)$ ] for each decision variable adjustment in order to apply Eqs. 14 and 15 to estimate the first and second derivative terms of Eq. 13. A cycle consists of adjustments to all of the decision variables, excluding any that are fixed at set values by options on the *FE* and *FP* records.

The primary stop criteria are based on no further change occurring in each of the decision variables or in the objective function between cycles. A maximum limit is also set on the number of cycles. The cycles continue until occurrence of any one of the following conditions reflected in the stop criteria.

1. No decision variable changes by more than 0.01 percent and the objective function changes by no more than 0.01 percent between a cycle and its preceding cycle.
2. The objective function changes by no more than 0.01 percent between each two successive cycles over a total sequence of four cycles.
3. The maximum limit of  $FE(12)$  cycles is reached where the default limit is 500 cycles if the entry  $FE(12)$  is blank on the *FP* record.

The 13 decision variables  $B(m)$  and  $BX$ ,  $5 \times N$  decision variables  $X(i,j)$ , and  $U(1)$  and  $U(2)$  may be included in the search.  $DX$  is optimized by another algorithm. Selected parameters can be fixed at either user-specified values or defaults. Thus, certain parameters can be removed by the user from the list of decision variables being optimized. The optimization based parameter calibration may be repeated for low, medium, high, and flood flows.

*FE* and *FP* records facilitate a calibration process in which flows may be categorized as low, medium, and high flows for two purposes. Different sets of model parameters may be adopted for low, medium, high, and flood flows. Multiple flow zones may also be employed in defining the objective function used to optimize a single set of parameter values.

The step size  $\Delta x$  in Eqs. 14 and 15 may be set by *FP* record FEX(1) and FEX(2) as a dimensionless fraction of the latest value of  $B(m)$  or  $X(i,j)$  in the iterative computations. The default  $\Delta x$  are replaced with the optional FEX(1) and FEX(2) if so specified on the *FP* record. FEX(1) and FEX(2) are adopted for the entire search except for when  $\Delta x$  is increased to deal with a zero second derivative. Defaults for FEX(1) and FEX(2) are as follows.

$\Delta x = \text{greater of } FEX(1) \times B(m) \text{ or } 1.0 \text{ acre-foot/month when } B(m) \text{ are adjusted.}$

$\Delta x = \text{greater of } FEX(2) \times X(i,j) \text{ or } 0.000001 \text{ when } X(i,j) \text{ are adjusted.}$

The Eqs. 14 and 15 step size  $\Delta x$  for the other optimization decision variables (model parameters) are fixed in *HYD* with no input options for changing  $\Delta x$ .

Eq. 13 cannot be applied if  $f''(x)$  is zero since dividing by zero is not allowed in mathematics. The Newton-Raphson formula (Eq. 13) is also not valid with a negative  $f''(x)$ . The second derivative  $f''(x)$  represents a change in the slope of  $f(x)$ . Occurrence of a flat segment of  $f(x)$  with non-zero slope  $f'(x)$  and but zero change in slope  $f''(x)$  is possible. The *HYD* optimization routine includes a feature to deal with this situation. If Eq. 15 results in a  $f''(x)$  of zero,  $\Delta x$  is doubled and the computations are repeated. If the slope remains flat in the expanded range,  $\Delta x$  is doubled again as necessary up to five times to achieve a non-zero  $f''(x)$ . If  $f''(x)$  still remains at zero, either  $x$ ,  $x+\Delta$ , or  $x-\Delta x$  is adopted based on which has the smallest  $f(x)$ .

The search algorithm ensures that the decision variables are constrained within specified limits. Other auxiliary features deal with irregularities in the gradient search behavior due to complex non-smooth relationships between the decision variables and objective function.

### **Parameter Calibration**

Calibration consists of determining an optimal set of values for model parameters fitted to the TWDB precipitation and evaporation datasets that allows the period-of-analysis naturalized flows from a TCEQ WAM System dataset to be reproduced as closely as possible with the model. The resulting calibrated model is then applied to extend the naturalized flows. Considerable flexibility is provided by *WRAP-HYD* for experimentation. However, the *HYD* calibration features can also be applied in an organized structured manner.

Parameter calibration features of *HYD* are controlled by *FE*, *FP*, *FZ*, *FR*, *QD*, and *QA* records. The results of the parameter calibration is a subset of *UB*, *BM*, *B1*, *B2*, *B3*, *B4*, *XM*, *X1*, *X2*, *X3*, *X4*, *RC*, and *FX* records which are combined with *FE*, *FZ*, *ZR*, *QD*, and *QA* records to extend the naturalized flows. Many of these records are optional, and some may not be needed depending on options selected. Two levels of calibration incorporating multiple stages are performed. The calibrated model created in level 1 consists of Eqs. 1-5 with values determined for all of their parameters. The basic model created in level 1 could be applied without further adjustments. The subsequent calibration level 2 methods consist of additional adjustments to improve model accuracy in reproducing statistical characteristics of the known naturalized flows.

#### **Parameters of the Flow Model**

Different parameters are optimized in the two levels of the calibration process. The results of the primary level 1 of the calibration process are recorded on *BM*, *B1*, *B2*, *B3*, *B4*, *XM*,

$X1$ ,  $X2$ ,  $X3$ ,  $X4$ , and  $UB$  records along with the  $FE$  record. Additional parameters incorporated in subsequent optional level 2 of the calibration process are recorded on  $RC$ ,  $FX$ , and  $UB$  records.

The initial primary level 1 of the calibration process consists of an automated optimization procedure that determines values for the parameters of Eqs. 1, 2, 3, 4, and 5.

- $B(m,z)$  and  $BX(z)$  are base flow parameters in Eq. 4.  $B(m,z)$  for each of the 12 months of the year may be calibrated and  $BX(z)$  fixed at the default of 1.0. Alternatively,  $BX(z)$  may be calibrated and  $B(m,z)$  fixed. Without flow zones, values of  $B(m)$  are stored on  $BM$  records.  $B(m,z)$  for low, medium, high, and flood flows are stored on  $B1$ ,  $B2$ ,  $B3$ , and  $B4$  records, respectively. The 12  $B(m)$  on a  $BM$  record or up to  $4 \times 12 = 48$   $B(m,z)$  recorded on  $B1$ ,  $B2$ ,  $B3$ , and  $B4$  records are flow volumes in units of acre-feet/month. The multiplier factors  $BX(z)$  are dimensionless.
- $X(i,j,z)$  are dimensionless factors in Eq. 2 that range between 0.0 and 1.0. Without flow zones, the five calibrated  $X(i,j)$  for each of the  $N$  quadrangles are recorded on  $XP$  records. Calibrated  $X(i,j,z)$  for low, medium, high, and flood flows are recorded on  $X1$ ,  $X2$ ,  $X3$ , and  $X4$  records, respectively, for each of the  $N$  quadrangles.
- $DX$  is a dimensionless multiplier factor in the drought index (Eq. 5).  $DX$  is calibrated at the end of the automated optimization procedure after  $B(m,z)$ ,  $BX(z)$ ,  $X(i,j,z)$ ,  $U(1)$ , and  $U(2)$  have been set. *HYD* provides various options for calibrating  $DX$ .
- $U(1)$  and  $U(2)$  in Eq. 1 are dimensionless parameters that model the nonlinear response of stream flows to precipitation from the perspective of the combined total runoff from the entire watershed combining all of the quadrangle components.

The second level of the calibration process results in values for the following optional parameters designed to further refine the flow model.

- Flow adjustment factors  $FX(r)$  for up to 12 flow ranges recorded on a  $FX$  record.
- Regression coefficients recorded on a  $RC$  record.
- Two optional parameters  $ZF(1)$  and  $ZF(2)$  on the  $UB$  record designed to improve the modeling of zero and close-to-zero flows.

The decision variables are constrained within the calibration procedure to the following ranges which realistically reflect the previously discussed physical concepts being modeled. Precipitation-runoff parameters may be calibrated separately for the four flow zones or subsets of the four zones. The index  $z$  is sometimes omitted from the variable notation in the description of the calibration process throughout this report. Base flow parameters are not referenced to flow zones.  $FX(r)$  factors on the  $FX$  record refer to 12 flow ranges rather than the four flow zones.

<u>Base Flow Parameters</u>	<u>Flow Equation Rainfall-Runoff Parameters</u>		<u><math>FX</math> Record Adjustment Factors</u>
	<u>Multiplier Factors</u>	<u>Exponents</u>	
$0.0 \leq B(m,z)$	$0.0 \leq U(1) \leq 1.0$	$0.7 \leq U(2) \leq 1.4$	$0.0 \leq FX(r)$
$0.0 \leq BX(z) \leq 1.0$	$0.0 \leq X(i,1,z) \leq 1.0$	$0.0 \leq X(i,2,z) \leq 1.0$	
$0.0 \leq DX \leq 6.0$	$0.0 \leq X(i,3,z) \leq 1.0$	$0.0 \leq X(i,5,z) \leq 1.0$	
	$0.0 \leq X(i,4,z) \leq 1.0$		

## Organization of the Parameter Calibration Procedure

WRAP-HYD provides flexibility for dividing flows into up to four flow zones (low, medium, high, flood) or subsets of these flow zones. The two primary strategies for defining flow zones are outlined in Figures 6.1 and 6.2 and Tables 6.1 and 6.2. However, other strategies can also be devised in assigning values to the limits LU, ML, MU, HL, HU, and FL.

Values for the model parameters are determined based on two separate levels of calibration options. The second level of computations is a set of optional refinements that follow completion of the first level that are based on comparing computed and known flows.

1. The first level is an optimization-based automated calibration process composed of multiple 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 (Eqs. 1, 2, 3, 4, 5). 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 factors designed primarily to improve the accuracy of the model in reproducing the statistical characteristics of the original naturalized flows. The primarily objective is to reproduce the mean, standard deviation, and flow frequency curve as closely as possible.

Using optimization terminology, the *FE/FP/FZ* record automated parameter calibration procedure (level 1) consists of optimization algorithms that search for the set of values for the decision variables that minimize an objective function. *HYD* calibration features are designed for four separate optimization searches, using different objective functions, to develop different sets of parameter values for low, medium, high, and flood flows as delineated by the LU, ML, MU, HL, HU, and FL limits defined in Figures 6.1 and 6.2. The optimization process is performed in multiple stages controlled by *FE*, *FP*, and auxiliary records. Sequential stages of the calibration procedure begin with initial estimates of parameter values from preceding stages.

*HYD* includes features (level 2) for analyzing flows computed with the model resulting from the automated optimization-based calibration process. The model may be refined based on these analyses. The  $FX(r)$  for 12 flow ranges recorded on a *FX* record are adjustment factors. An optional regression and correlation analysis feature can be applied to evaluate and improve the model. Factors recorded on the *UB* record to refine the modeling of zero and non-zero flows can also be adopted. These level 2 calibration options are applied in the calibration process after completion of the level 1 model calibration. Likewise, in applying the model to extend flows, the level 2 features are applied to adjust the  $Q(t)$  resulting from applying Eqs. 1, 2, 3, 4, 5.

### **Optimization-Based Automated Parameter Calibration Procedure**

The automated optimization-based level 1 parameter calibration features of *HYD* consists of finding optimal values for the parameters of the flow model (Eqs. 1, 2, 3, 4, 5) by assigning initial estimates and then adjusting these estimates in an iterative search for an optimal set of parameter values. Conceivably, calibration could involve numerous trial-and-error iterative

executions of *HYD* while changing parameter values between executions. However, the automated optimization-based calibration capabilities of *HYD* are essential due to the complexities of fitting numerous interrelated parameters to large datasets. The *HYD* automated search procedure may be supplemented by experimentation with user-controlled trials.

### FE(2) Calibration Options

The options outlined in Table 6.3 are activated by FE(2) in *FE* record field 8. FE(2) options 1 through 11 control the automated parameter (level 1) calibration process. A blank *FE* record field 8 (FE(2)=0) means parameter values are provided on input records for the flow extension computations applied in both the level 2 calibration and the final flow extension.

Table 6.3  
FE(2) Calibration Options

FE(2) Option	Flow Zone	Initial Values	Combination
1	low	computed	none
2	medium	computed	none
3	high	computed	none
4	flood	computed	none
5	low	FE(2) option 1	Table 6.2
6	medium	FE(2) option 2	Table 6.2
7	high	FE(2) option 3	Table 6.2
8	flood	FE(2) option 4	Table 6.2
9	non-flood	computed	none
10	flood	computed	Table 6.1
11	none	computed	none

The options controlled by *FE* record switch FE(2) listed in Table 6.3 address two key issues in applying the automated search optimization algorithms to calibrate values for the parameters U(k), B(m), BX, and X(i,j).

- Search algorithms must begin with an initial estimate for each of the decision variables.
- Although the LU, ML, MU, HL, HU, and FL limits (Figures 6.1 and 6.2) can be referenced to known naturalized flows in the calibration computations, there are no known flows during the period-of-extension. Flows are synthesized following the rules outlined in Tables 6.1 or 6.2 based on computing and combining low, medium, high, and flood flows. The LU, ML, MU, HL, HU, and FL limits optionally may refer to either known or computed flows during parameter calibration but must refer to computed flows during the final flow extension computations.

The FE(2) options differ in regard to dealing with these two issues. Options 1, 2, 3, 4, and 9 reference flow zones to known flows and apply the flow model to compute Q(t) without

needing the combining rules of Tables 6.1 and 6.2. Options 5, 6, 7, 8 implement the combining rules of Table 6.2 and option 10 implements the combining rules of Table 6.1 while defining flow zones with reference to computed flows. FE(2) option 11 does not use the zone feature.

Options 1, 2, 3, 4, 9, and 11 compute  $Q(t)$  directly without needing the rules of Tables 6.1 and 6.2. Flow zones for options 1, 2, 3, 4, and 9 are defined based on known flows.

Options 5, 6, 7, and 8 compute flows  $Q(t)_L$ ,  $Q(t)_M$ ,  $Q(t)_H$ , and  $Q(t)_F$  for each month  $t$  and apply the rules of Table 6.2 to determine the final  $Q(t)$ . Flow zones are defined based on computed flows. Starting estimates are from preceding options 1, 2, 3, 4 optimizations.

Option 10 is based on computing two flows  $Q(t)_X$  and  $Q(t)_F$  for each month  $t$  and applying the rules of Table 6.1 to determine the final  $Q(t)$ . Flow zones are defined based on computed flows. Starting estimates of parameter values are computed.

The FE(2) options may be combined in various ways in a single execution of HYD. Options 5, 6, 7, 8 are designed to be applied in combination with options 1, 2, 3, 4. Option 10 is applied in combination with option 9. Options 1, 2, 3, 4 and options 5, 6, 7, and 8 are based on defining low, medium, high, and flood flow zones as described in Figure 6.2 and Table 6.2. Options 9 and 10 are based on defining non-flood and flood flow zones as described in Figure 6.1 and Table 6.1. Option 11 performs calibration computations without reference to flow zones.

Stream flows vary dramatically from zero or near-zero to extremely high flood flows. Calibrating a single model to accurately represent the full range of flows is difficult. Up to four flow models can be created for different ranges of flow. However, combining the models based on defining flow zones referenced to computed flows introduces additional inaccuracies. Variations of the following three strategies for modeling flows by flow zone may be adopted.

1. Application of FE(2) option 1 to develop a single flow model without subdividing flows into zones.
2. Combination of FE(2) options 9 and 10 to subdivide flows into two zones. A model for each of two zones is calibrated one time.
3. Combination of FE(2) options 1, 2, 3, 4 and options 5, 6, 7, 8 to subdivide flows into four zones. Models for each of the four zones may be iteratively calibrated any number of times with latest results serving as starting values for the next iteration.

The second alternative based on FE(2) options 9 and 10 is the recommended default standard strategy which is illustrated by the example presented later. This recommended strategy consists of combining two *FE* records, the first with FE(2) option 9 and the second with option 10, along with auxiliary supporting records in a single execution of *HYD*.

The more complex third strategy should be investigated if the second strategy does not yield satisfactory results. This strategy combines at least eight *FE* records but perhaps many more *FE* records, along with supporting records. An initial four sets of parameter values are determined based on FE(2) options 1, 2, 3, and 4 for low, medium, high, and flood flows, respectively. Next, options 5, 6, 7, and 8 are applied starting with initial parameter values from the preceding application of options 1, 2, 3, and 4. This process is iteratively repeated with any number of additional options 5, 6, 7, and 8 calibrations starting with the latest parameter values.

## General Level 1 Optimization Strategy

Mathematical optimization techniques are widely employed in the calibration of various types of computer simulation models. The *HYD* flow model calibration problem is similar to many other complex models in regard to the existence of an essentially infinite number of possible solutions, many of which are essentially indistinguishable in their level of optimality. Although many bad or clearly non-optimal solutions exist, there is not necessarily a single optimum solution. The *HYD* flow model has many parameters. Many different combinations of values for these parameters will result in similar values for the objective criteria. One of many different solutions that yield near-optimal results will be determined by the optimization procedure with a particular set of calibration options selected. Activating alternative calibration options may result in significantly different values for the individual parameters that in combination yield similar levels of optimality in reproducing flows.

Strategies for applying the automated optimization-based calibration capabilities are formulated by combining options associated with the following *HYD* features.

- Specification of flow zones as illustrated by Figures 6.1 and 6.2 and Tables 6.1 and 6.2 using the flow limits entered on the *FZ* record.
- Formulation of objective functions based on Eqs. 8, 9, 10, 11, and 12 using the weighting factors entered on the *FP* record.
- Combining of the calibration options listed in Table 6.3 which are selected by the entry for FE(2) on the *FE* record.
- Combining options for baseflow and drought index parameter calibration based on options controlled by entries on the *FE* record.

*HYD* provides flexibility for experimentation and formulation of alternative calibration strategies. The example presented later represents a structured approach that could be adopted in general for broad applicability. Regardless of alternative strategies pursued, the automated optimization-based parameter calibration procedure is based on the following computations.

## Optimization Computations Comprising Level 1 of the Calibration Process

The automated parameter calibration computations performed in a single execution of *HYD* are outlined as follows. The level 1 calibration computations performed by *HYD* proceed sequentially through the following four steps.

1. Initial estimates are developed for the parameter values using primarily enumeration algorithms or preset defaults. Conceivably these preliminary estimates could be adopted for the flow extension without proceeding to stage 2 and 3 listed next. However, both preciseness and accuracy would likely be very limited. The purpose of continuing to stages 2 and 3 is to improve model preciseness and accuracy. Values are assigned to all parameters in stage 1 though these values may be approximate.
2. A univariate gradient search algorithm using the Newton-Raphson method starts with the initial parameter estimates and cyclically searches for improved values. The

gradient search optimization methodology efficiently searches for optimum values for five  $X(i,j)$  for  $N$  quadrangles,  $B(m)$  for each of the 12 months,  $BX$ ,  $U(1)$ , and  $U(2)$ .

3. A final set of enumeration algorithms test the univariate gradient search results and may result in further refinements.
4. The drought index factor  $DX$  is calibrated as the final stage of the optimization.

The gradient search optimization methodology is very computationally efficient, requiring relatively minimal computer runtime. However, search algorithms are subject to resulting in local rather than global optima. The search algorithm may reach different sets of final optimal values of the decision values with searches that start with different initial starting values. Good initial estimates for the decision variables may be required for the gradient search algorithm to find a near-global optimum.

The overall approach outlined below includes methods for determining valid values for the parameters that are reasonably close to optimum prior to starting the gradient search procedure. Computed values of the parameters resulting from any stage of the computations remain in computer memory for use as starting values for the next stage. The univariate gradient search optimization procedure starts with initial estimates for all of the decision variables and adjusts the values for  $U(1)$ ,  $BX$ ,  $B(m)$ , and  $X(i,j)$ .

Initial estimates for decision variables (model parameters) used to initiate the gradient search optimization may come from the following sources.

- Initial values can be specified on input records.
- Defaults for most of the parameters are automatically set if no other values are provided through the various options.
- FE(2) option 5, 6, 7, and 8 searches begin with initial values that are in computer memory from preceding FE(2) option 1, 2, 3, and 4 searches or preceding option 5, 6, 7, and 8 searches. Any number of option 5, 6, 7, and 8 searches can be performed in a single execution of *HYD* with each search starting with the most recent parameter values placed into memory.
- For FE(2) option 1, 2, 3, 5, 9, and 11 searches, an initial set of initial parameter values are computed as follows. The methodologies for developing initial estimates for parameter values to begin the gradient search are completely different for the different parameters.

#### Initial Estimates of Model Parameters Assigned as Defaults or with Input Records

The decision variables are listed below with the initial defaults that are automatically assigned by *HYD* subject to change by input options. The initial defaults may also be the final parameter values if no calibration options are activated to change them. Any of these model parameters may also be assigned fixed values on input records and thus excluded from the set of decision variables included in the optimization.

$U(1)$ ,  $U(2)$      Default = 1.0.     Set on *UB* record or optimized.

X(i,j)	Default = 1.0. Set on <i>XP</i> records or optimized.
B(m)	Default = 0.0. Set on <i>BM</i> record or optimized.
BX	Default = 1.0. Set on <i>UB</i> record or optimized.
DX	Default = 1.0. Set on <i>FE</i> record or optimized.

### Base Flow Parameters B(m) and BX

Although *HYD* allows B(m) and BX to be optimized concurrently, normally either BX or the 12 B(m) or will be optimized with the other set at fixed values. Calibration of the drought index factor DX is the same regardless of the strategy adopted for combining B(m) and BX.

Eq. 5 models base flow as  $BF(t)=B(m) \times BX \times DI(t)$  where BF(t) represent seasonally varying long-term base flows that respond slowly to precipitation. During low flow conditions, base flows may represent most or all of Q(t). The twelve B(m)×BX in acre-feet/month are multiplied by a dimensionless drought index  $[0.0 \leq DI(t) \leq 1.0]$  that lowers the seasonal base flows during dry periods. BX is a dimensionless factor between 0.0 and 1.0 with a default of 1.0. The twelve B(m) may be optimized with BX set at 1.0, allowing the possibility of large variations between the twelve B(m) including the possibility of B(m) of zero in some months. Alternatively, the twelve B(m) may be treated as fixed maximum limits and BX optimized.

The means of the six lowest flows during the period-of-analysis are automatically computed by *HYD* for each of the 12 months. For example, for a period-of-analysis of 1940-1997, B(1) is computed as the average of the six smallest of the 58 January naturalized flow volumes from the WAM dataset. B(2) is the mean of the six lowest of the 58 known February flows and so forth. B(12) is the average of the six smallest December naturalized flows during the 58-year 1940-1997 period-of-analysis.

The initial estimate for the twelve B(m) may be set at the means of the six lowest flows or alternatively as the means of the six lowest flows constrained to not exceed a maximum limit specified on the *FE* record. The B(m) may be treated as 12 parameters to be calibrated in the optimization computations. Alternatively, the twelve B(m) may be treated as fixed maximum limits, and BX calibrated ( $0.0 \leq BX \leq 1.0$ ). Baseflow = B(m)×BX×DI(t)

The default for BX is 1.0. If optimized, the initial estimate for BX is set in the enumeration process described next. If optimized, the initial estimates of for B(m) are adjusted in the enumeration process. The initial estimates are used in the same manner to start the gradient search procedure regardless of how they are determined.

### Default Enumeration Option for Initial Estimates for U(1), U(2), X(i,j), B(m), and BX

The term *enumeration* is adopted here to refer to algorithms that compute and compare objective function values for numerous values of a decision variable or combinations of values for multiple decision variables. The numerous alternative values of the decision variables are enumerated simply by incrementing the variable by a set quantity over a specified range. For example, incrementing by 0.1 in the range of 0.0 to 1.0 results in the following eleven alternative values for the variable X(i,j): 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0. These eleven

alternative values could be considered for each of twelve  $X(i,j)$  (three  $X(i,j)$  for each of four quadrangles) resulting in  $9^{12} = 3,138,428,376,721$  combinations.

Computer execution time limits the extent to which combinations can be enumerated. Complete detailed enumeration of all possible combinations of parameter values is not feasible because the combinations are too numerous for consideration even with high speed computers. The number of combinations of variables generated becomes extremely large as the number of variables becomes larger and the incremental step size is made smaller. The alternative *HYD* enumeration schemes are limited in detail and extent to preclude excessive computer execution time. Computer execution time can vary greatly with different enumeration options. The computer runtime for an execution of *HYD* in calibration mode may vary from several minutes to many hours depending on the enumeration options activated. The univariate gradient search is much more efficient. The enumeration algorithm provides starting values for the subsequent more precise and efficient gradient search algorithm.

The standard recommended default option for determining initial values for  $U(1)$ ,  $U(2)$ , and  $X(i,j)$  is based on enumeration. The enumeration algorithm can also be used to develop initial values for  $B(m)$  and/or  $BX$  along with  $U(1)$ ,  $U(2)$ , and  $X(i,j)$ . Initial estimates are developed for  $X(i,1)$ ,  $X(i,3)$ , and  $X(i,4)$  using an enumeration strategy. The same values may be assigned to all of the  $N$  quadrangles, with the subsequent univariate gradient search optimization allowing the  $X(i,j)$  to vary between the  $N$  quadrangles. Alternatively, the enumeration can be applied to  $X(i,j)$  for all the  $N$  quadrangles or to a subset consisting of  $ND$  of the  $N$  quadrangles.

The enumeration method consists of comparing objective function values computed for numerous combinations of  $U(1)$ ,  $U(2)$ ,  $X(i,1)$ ,  $X(i,3)$ ,  $X(i,4)$ , and  $BX$ . The exponents  $X(i,2)$  and  $X(i,5)$  are set at 1.0 in the initial estimates. All or any subset of these variables can be included in the enumeration. Any variables not included in the enumeration are set at fixed values. The results of the enumeration algorithm are initial estimates that are adjusted in the subsequent gradient search algorithm and other auxiliary enumeration procedures.

Two enumerations are performed. In the first enumeration, the decision variables are incremented as follows.

$$\begin{aligned} U(1) &= 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 \\ U(2) &= 0.9, 1.0, 1.1, 1.2, 1.3 \\ X(i,1) &= 0.6, 0.7, 0.8, 0.9, 1.0 \\ X(i,3) &= 0.0, 0.1, 0.2, 0.3, 0.4 \\ X(i,4) &= 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 \\ BX &= 0.0, 0.2, 0.4, 0.6, 0.8, 1.0 \end{aligned}$$

This enumeration results in  $36,000 \times N^3$  ( $8 \times 5 \times 5N \times 5N \times 6N \times 6 = 36,000N^3$ ) combinations of values for the decision variables where  $N$  is the number of quadrangles. With only one quadrangle, there are 36,000 combinations. With seven quadrangles, there are 12,348,000 combinations. The objective function is computed for each of the combinations of values of the decision variables. The combination that results in the smallest value of the objective function (Eq. 8) is selected for use in the second enumeration. The decision variable values reflect only one significant figure in the first enumeration.

The second enumeration adds an additional digit of precision to the values of the decision variables. The entry for FE(10) on the *FP* record selects between alternative options 1, 2, 3, and 4 for the second enumeration. For the default option, the  $X(i,j)$  are incremented in steps of 0.01 for a distance of 0.06 on both sides of the values selected in the first enumeration. For example, if  $U(1)$  of 0.8 is selected in the first enumeration, the following values of  $U(1)$  are considered in the second enumeration:

0.74, 0.75, 0.76, 0.77, 0.78, 0.79, 0.80, 0.81, 0.82, 0.83, 0.84, 0.85, and 0.86.

FE(10) option 1 results in up to  $13^{3+3N}$  combinations or sets of decision variable values. With only one quadrangle, this is 4,826,809 combinations. With seven quadrangles, there are up to  $5.428 \times 10^{26}$  combinations. However, most of the decision variables are each constrained to the range of 0.00 to 1.00. The number of combinations is reduced during the computations if and when reaching the limits 0.00 or 1.00. The combination resulting in the smallest value of the Eq. 8 objective function is selected for use as the initial estimates of the decision variables. Other FE(10) options change the range and increments of the enumeration which may significantly affect computer runtime.

The FE(10) and FE(11) options deal only with computing initial estimates for the decision variables (calibration parameters). All of the decision variables, including separate  $X(i,j)$  for each individual quadrangle, are optimized in the subsequent gradient search. The key issue motivating consideration of the tradeoffs between accurate initial parameter estimates and computer runtime is the tendency for search algorithms to converge on local rather than global optima. Better initial parameter estimates improve the reliability of the gradient search algorithm in finding a near-global optimum set of parameter values.

The five  $X(i,j)$  for each of the  $N$  individual quadrangles( $i$ ) are all optimized in the gradient search. In developing the initial estimates for  $X(i,j)$  to start the gradient search, the  $X(i,3)$ , and  $X(i,4)$  are set at 1.0 for all  $i$  and are not optimized in the enumeration algorithm.

FE(11) on the *FP* record provides options for handling the  $N$  quadrangles in developing initial estimates for  $X(i,1)$ ,  $X(i,3)$ , and  $X(i,4)$ . The default FE(11) option 1 consists of optimizing a single set of  $X(i,1)$ ,  $X(i,3)$ , and  $X(i,4)$  which are applied for all quadrangles. FE(11) option 2 consists of optimizing a different sets of  $X(i,1)$ ,  $X(i,3)$ , and  $X(i,4)$  for each individual quad for  $ND$  quads that may include all  $N$  quads or a subset thereof. For a watershed encompassing several quadrangles, switching to FE(11) option 2 dramatically increases the number of combinations included in the enumeration and the corresponding computer runtime.

Computer runtime is reduced dramatically by grouping quadrangles together in the enumeration algorithm.  $N$  denotes the number of quadrangles listed on the *QD* record. The first  $ND$  quadrangles listed comprise a subset of the  $N$  quadrangles.  $ND$  and  $N$  are entered in *QD* record fields 2 and 3. If *QD* record field 2 is blank or zero,  $ND$  defaults to  $N$ . With FE(11) option 2, there are  $ND$  enumerations. The first  $ND$  less one quadrangles are each enumerated separately. The  $ND$ th enumeration combines all remaining quadrangles. Thus, FE(11) option 2 is relevant only for control points with more than one quadrangle. FE(12) option 2 with  $ND$  set at 1 is equivalent to FE(11) option 1. With  $ND$  of 5 and  $N$  of 11, the first 4 quadrangles listed on the *QD* record are each optimized individually in the enumeration algorithm. The fifth enumeration optimization applies to all of the remaining seven quadrangles.

The parameter ND entered in *QD* record field 2 is used for two different unrelated purposes: (1) enumeration options as discussed above and (2) drought index computations. ND affects the enumeration algorithm only if FE(11) option 2 is activated. However, with FE(11) option 2 activated, ND also affects the unrelated drought index computations. Only the first ND quadrangles are included in the drought index computations.

Baseflow is defined by Eq. 5 as:

$$BF(t) = B(m) \times BX \times DI(t)$$

Typically either BX or the twelve B(m) will be optimized but not both. However, the multiplier factor BX is included in the enumeration for optimizing B(m) even if BX itself is not optimized. If the B(m) are optimized, a single multiplier factor X is included in the enumeration algorithm, with  $X=BX$  and B(m) treated as a maximum limit. At the completion of the enumeration,  $B(m)=X \times B(m)$  and BX is set at either its default of 1.0, a value from the *BX* record, or an optimized value. Whereas the gradient search optimizes the B(m) as 12 separate decision variables, the enumeration adjusts the 12 B(m) in the same proportion by a multiplier factor.

#### Alternative Option for Initial Estimates of U(k) and X(i,j)

Option 5 activated by FE(10) on the *FE* record develops a single initial set of X(i,j) which are applied to all of the N quadrangles along with U(1) and U(2) of 1.0. Option 5 is much more approximate than the alternative enumeration schemes of FE(10) options 1, 2, 3, and 4 but requires less computer runtime. With FE(10) option 5, U(1) and U(2) and the exponents X(i,2) and X(i,5) are set at 1.0, converting the flow equation to linear. Q(t) less base flow BF(t) is assumed to come from solely precipitation in the same month (t). X(i,1) and X(i,3) for the N quadrangles are all set at the same fractions F<sub>1</sub> and F<sub>2</sub> defined by Eq. 17. The initial estimates for B(m) and X(i,j) result in the conversion of Eq. 1 to Eq. 16.

#### Current Month Precipitation

$$\begin{aligned} X(i,1) &= F_1 & \text{for } i = 1 \text{ to } N \\ X(i,2) &= 1.0 & \text{for } i = 1 \text{ to } N \\ X(i,3) &= F_2 & \text{for } i = 1 \text{ to } N \end{aligned}$$

#### Preceding Month Precipitation

$$\begin{aligned} X(i,4) &= 1.0 & \text{for } i = 1 \text{ to } N \\ X(i,5) &= 1.0 & \text{for } i = 1 \text{ to } N \end{aligned}$$

$$Q(t) = \left( \sum_{i=1}^N P(i,t) - F_1 \times P(i,t) - F_2 \times E(i,t) \right) + B(m) \quad (16)$$

$$F_1 = \frac{\bar{P} - \bar{Q} - (F_2 \times \bar{E}) + \bar{C}(m)}{\bar{P}} \quad \text{and} \quad F_2 = 0.2 \times \left( \frac{\bar{P}}{\bar{E}} \right) \quad (17)$$

$\bar{Q}$ ,  $\bar{P}$ , and  $\bar{E}$  in Eq. 17 are the period-of-analysis means of the volumes of naturalized flow Q(t), precipitation P(i,t), and evaporation E(i,t) during the TL low flow, TM medium flow, or TH high flow months as specified by FE(2) on the *FE* record. F<sub>1</sub> and F<sub>2</sub> are the default initial estimates of X(i,1) and X(i,3). Equations 16 and 17 are based on a long-term volume balance combined with the arbitrary assumption that 20 percent of the precipitation is loss through the evaporation term of Eq. 16. The period-of-analysis mean of the computed flows closely approximates the mean of the known flows with these initial parameter values.

## Univariate Gradient Search Optimization

The univariate gradient search methodology is described earlier. The 12 B(m), BX, 5N X(i,j), U(1), and U(2) are calibrated together in the search procedure. All of the decision variables except DX can be optimized in the search algorithm. The algorithm begins with initial values of the decision variables determined by the options outlined in the preceding discussion and applies Eq. 13 in a iterative search for improved values that minimize the specified objective function (Eq. 8). Details of the search are defined primarily by the specification of the W weighting factors for Eq. 8 on the *FP* record and selection of the FE(2) options in Table 6.3.

## Final Testing and Refinements to Optimization Results

The univariate gradient search adjusts all of its decision variables in each cycle, thus capturing the interactions between the variables in the optimization process. After satisfying the stop criteria and thus completing the search, the B(m), BX, X(i,j), and U(2) are further tested and refined as follows. Each variable is tested by itself. Very small incremental increases and decreases [ $0.0001 \times B(m)$ ,  $0.0001 \times X(i,j)$ ,  $0.001 \times BX$ ,  $0.001 \times U(2)$ ] to the value assigned to the decision variable are made to test whether the changes improve the objective function OF. The decision variable is incrementally increased as long as OF function improvements occur, with a limit of 1,000 incremental increases. Likewise, the decision variable is incrementally decreased as long as OF function improvements occur to a limit of 1,000 incremental decreases.

## Calibration of Drought Index Multiplier Factor DX

Since the drought index DI(t) focuses specifically on modeling lower than normal flows, the parameter DX in Eq. 5 is calibrated at the end of the automated calibration process using a different objective function. The entry DX in *FE* record field 17 specifies the method for setting the parameter DX in the Eq. 5 drought index. DX may be set as the number entered in *FE* record field 17 or default to 1.0 with a blank field. Alternatively, the drought index may be deactivated. Alternatively, DX may be incorporated in the automated parameter calibration procedure.

DX is optimized as the end of the level 1 automated parameter calibration procedure after values have been adopted for all other variables. DX is set at 1.0 for the objective function evaluations of the preceding optimization algorithms. Options for calibrating DX are based on an enumeration that extends from 0.000 to 6.000 in increments of 0.001 with the OF being computed for each of the 6,001 values of DX. The DX that minimizes the OF is adopted.

The following DX calibration options are activated by *FE* record field 17.

1. Option 1 uses the same objective function OF as the other optimization procedures except only the Zs for low flows are included. Medium, high, and flood flows are excluded.
2. Option 2 uses exactly the same objective function as the other optimization procedures including all of the component Zs.
3. Option 3 is based on counting the number of months in which the known flows and computed flows are at or below ZU. The objective function consists of minimizing the difference between the counts for computed flows and known flows.

Whereas the optimization procedures for the other decision variables all use the same objective function, a different OF can be formulated specifically for calibrating DX. Option 1 uses only the low flow components of the OF. Option 2 uses the complete OF. The flow zone used in option 3 consists of flows at and below the limit ZU acre-feet/month entered in *FZ* record field 3. This flow zone is used only for calibrating DX. ZU will normally be the smallest flow limit on the *FZ* record and close zero. DX calibration option 1 uses the conventional low flow zone defined by LU on the *FZ* record.

### **Second Level of Analyses and Refinements**

The flow model (Eqs. 1, 2, 3, 4, 5) with parameter values determined in the level 1 calibration process as outlined in the preceding section may be adopted for the flow extension without further modification. However, program *HYD* also includes level 2 options to analyze and further adjust the flows computed with the flow extension model. In the level 2 calibration, *HYD* is activated with *FE* record field 8 blank ( $FE(2)=0$ ) and the parameters developed in the level 1 calibration provided on input records. The level 2 flow adjustment options result in adoption of additional parameters which are recorded on *FX*, *RC*, and/or *UB* records.

The accuracy of the flow extension model is evaluated by comparing the period-of-analysis flows computed with the calibrated model with the known naturalized flows from the WAM dataset. The computed and known naturalized flows are processed through *SIM* and *TABLES* to develop time series and frequency tables that facilitate comparisons. HEC-DSSVue is used to plot the flows. *HYD* also creates summary tables and metrics in the message HMS file for use in comparing computed and known flows. In addition to the comparative analyses of model results, these metrics may be used to modify the flow model.

The calibration process attempts to develop a model that reproduces the known naturalized flows as closely as possible. However, the flows computed for each individual month are necessarily approximate. The WRAP/WAM System is designed for developing frequency and reliability relationships rather than precisely synthesizing the exact flow in a particular month. Likewise, the flow model calibration process is designed to capture the statistical characteristics of the naturalized flows. The level 2 calibration focuses on developing flow sequences with the correct means, standard deviations, and flow-frequency relationships.

#### **FX Record Factors**

In the level 2 calibration process,  $FX(r)$  ratios are automated recorded in table format in the *HYD* message HMS file and *FX* input record format in the HOT file. The multiplier factors  $FX(r)$  correspond to flow ranges defined by  $QR(r)$  on the *FR* record. The  $FX(r)$  are automatically computed and recorded on a *FX* record when *HYD* is executed in calibration mode. The *FX* record is then manually inserted into the *HYD* input HIN file used for the final flow extension. Flows are grouped by flow range.  $FX(r)$  are computed as the mean of known flows  $Q_K(t)$  divided by the mean of the corresponding computed flows  $Q_C(t)$ . In the flow extension, the flows computed with the flow equation (Eqs. 1, 2, 3, 4, 5) are multiplied by the  $FX(r)$  factors.

$$FX(r) = \frac{\overline{Q_K(t)}}{\overline{Q_C(t)}}$$

The standard recommended calibration procedure includes use of *FX* record  $FX(r)$  factors to improve the capability of the flow model to reproduce the mean, standard deviation, and flow frequency relationship of the known naturalized flows. Flows computed by the flow model (Eqs. 1, 2, 3, 4, 5) tend to be either high or low in general and particularly high or low in certain ranges of flow. The  $FX(r)$  provide adjustments to correct these tendencies.

The tables in the *HYD* message HMS file include the means of the known and computed flows. The ratio of the means of all the flows recorded as  $FX(13)$  can be used to adjust the computed flows to have exactly the same mean as the known flows. In extending the flows, as a last step, the computed flows are multiplied by the factor  $FX(13)$  entered in the second field of the *FX* record.  $FX(13)$  is applied to all flows after the 12  $FX(r)$  for the 12 individual flow ranges.

A 2FRE record frequency table for known naturalized flows may be created with the WRAP program *TABLES* even before the flow model is created. Likewise, upon completion and execution of the calibrated (level 1) flow model, a 2FRE frequency table can be developed with *TABLES* for the computed flows. The flow frequency relationships for known and computed flows, respectively, are represented by two flow range *FR* records.

With the two *FR* records in its input HIN file, *HYD* automatically develops the *FX* record. The *FX* record is then added to the *HYD* input HIN file to adjust the computed flows to better reproduce the flow frequency relationship of the known flows in the final flow extension.

The flow limits  $QR(r)$  may be referenced to either known flows  $Q_K(t)$  or computed flows  $Q_C(t)$ . Any flow quantities may be specified for the up to eleven  $QR(r)$  on a *FR* record. However,  $QR(r)$  with exceedance frequencies of 95%, 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, and 5% are recommended subject to combining ranges of low flows if necessary to deal with a large number of months with zero flow. With the ranges referenced to computed flows, the  $Q_C(t)$  are in the lowest range [ $Q_C(t) \leq Q_C(95\%)$ ] during 5 percent of the months, in the next lowest range [ $Q_C(95\%) < Q_C(t) \leq Q_C(90\%)$ ] during 5 percent of the months, in each of the highest two ranges during 5 percent of the months, and in each of the eight other ranges during 10 percent of the months.

Two *FR* records may be provided with the first defining a flow-frequency relationship for known flows and the second defining a flow-frequency relationship for computed flows. With only one *FR* record, the known flow  $Q_K(t)$  and corresponding computed flow  $Q_C(t)$  in a particular month ( $t$ ) are assigned to the same flow range. With two *FR* records, the flow ranges for specified exceedance frequencies are assigned for known flows and computed flows, respectively. Thus, the median (50%) known flow can be compared with the medium computed flow, the 90% known flow can be compared with the 90% computed flow, and so forth. The *FR* records are created based on frequency tables for naturalized flows developed with the program *TABLES* with a 2FRE record.

The up to twelve flow ranges defined by the up to eleven limits  $QR(r)$ , in acre-feet/month, entered on the flow range *FR* record are similar to the four flow zones defined on the flow zone *FZ* record but are used for different purposes. The *FZ* and *FR* record parameters are associated with level 1 and level 2 calibration, respectively.

### Parameters ZF(1) and ZF(2) for Adjusting Zero and Near-Zero Flows

The optional parameters ZF(1) and ZF(2) on the *UB* record are set as the very last step of the level 2 calibration process to assure that the model generates zero or near-zero flows in an appropriate number of months. ZF(1) and ZF(2) are flow volumes in acre-feet/month with defaults of zero. Any computed flows of magnitude ZF(1) or smaller are reduced by subtracting ZF(2). If subtraction of ZF(2) from a flow results in a negative number, the flow is set at zero.

### Regression and Correlation Analyses

Regression and correlation analyses of flows  $Q_C(t)$  computed with the flow model versus known flows  $Q_C(t)$  from the WAM dataset are activated with *FE* record FE(1) option 3. The correlation and regression coefficients recorded in the HMS file provide metrics for comparing computed flows with known flows. A regression model can optionally be applied using a *RC* record to develop an adjusted set of predicted flows as a function of the flows computed with the calibrated flow model. The *RC* record feature is not recommended as a standard component of the calibration procedure but is available for experimentation and supplemental analyses.

A nonlinear power function is applied to flows below a specified regression boundary flow RBF. Linear regression is applied to flows above the specified RBF level. Optionally, the RBF may be set at zero, and either the linear or nonlinear regression equation applied. *HYD* creates a table in the HMS file that tabulates regression and correlation coefficients for the regression boundary flow RBF set alternatively at the flow levels specified on the flow range *FR* record. The regression coefficients are also provided on *RC* records.

$Q_C$  are the flows in acre-feet/month computed with the flow model with previously calibrated parameters. In determining regression coefficients,  $Q$  are the known flows. In extending flows,  $Q$  are new improved estimates of the flows. The following power regression equation is applied to the  $Q_C$  that are less than 90% of the regression boundary flow RBF.

$$Q = A \times Q_C^B$$

The following linear regression equation is applied to the  $Q_C$  greater than 110% of RBF.

$$Q = A + B \times Q_C$$

For  $Q_C$  that fall between 90% and 110% of the RBF ( $0.9 \text{ RBF} \leq Q_C \leq 1.1 \text{ RBF}$ ),  $Q$  is computed as the average of the two values determined with the linear and power regression equations. The coefficients  $A$  and  $B$  for both the power and linear equations are provided in both a HMS file table and on *RC* records.

The regression coefficients  $A$  and  $B$  are computed by applying linear regression to the logarithms of the flows based on the standard methods described in statistics and numerical methods textbooks. The correlation coefficient is also included in the FE(1) option 3 regression and correlation coefficient table in the HMS file. The correlation coefficient is the square root of the coefficient of determination as defined in statistics and numerical methods textbooks. The correlation coefficient ranges between -1.0 and 1.0, with 1.0 indicating a perfect fit.

### **Example 6.1 – Flow Extension**

The Brazos River Basin was adopted as an initial case study in 2012 to develop and test the hydrologic period-of-analysis extension methodology [12, 13]. The hydrologic periods-of-analysis for several other WAMs have also been extended since then to further demonstrate and refine the methodology. The methodology continues to be applied to various river basins.

The WAM System dataset for the Brazos River Basin and adjacent coastal basin has the 77 primary control points shown in Figure 6.4. Two of these control points are adopted for this flow calibration and extension example. Control point LRCA58 is the USGS gage on the Little River near Cameron. Control point NAEA66 is the gage on the Navasota River near Easterly. LRCA58 and NAEA66 are representative of the 77 primary control points in the Brazos WAM. Thirteen of the 77 control points have watershed areas greater than the LRCA58 watershed area of 7,074 square miles. Thirty-five of the 77 control points have watershed areas greater than the NAEA66 watershed area of 925 square miles. The original hydrologic period-of-analysis is 1940-1997. The period-of-extension is 1998-2012.

The quadrangles encompassing the Brazos River Basin are shown in Figure 6.4. The watersheds above control points LRCA58 and NAEA66 are encompassed by the seven quadrangles and one quadrangle, respectively, listed in Table 6.4. The watershed areas are delineated and the areas in square miles are estimated based on overlaying watershed and quadrangle maps. The quadrangle identifiers and watershed areas encompassed within each quadrangle, in square miles, are included in the *HYD* input HIN file on *QD* and *QA* records.

#### **HYD, SIM, and TABLES Input Files**

The following *HYD* input files are used in combination with a HIN file.

- FLO file with 1940-1997 naturalized flows at control points LRCA58 and NAEA66
- Precipitation.PPP file with the complete TWDB precipitation dataset
- Evaporation.EEE file with the complete TWDB evaporation dataset

*HYD* records the generated flows in its FLOW(control point, year, month) array which can be output in the various optional *IN* record formats in a FLO and/or HOT output file or as a DSS file as specified on the job control *JC* record. *SIM* and *TABLES* are used to develop frequency tables for comparing computed and known flows. *HEC-DSSVue* is used with the DSS output file created by *HYD* to plot the flows. The HEC-DSSVue plots and *TABLES* frequency tables along with tables created by *HYD* in its message HMS file provide information for comparative analyses of computed versus known flows during the calibration process.

The WRAP programs *SIM* and *TABLES* are used to develop frequency tables for comparing computed and known flows during the model calibration process. *HYD* creates a *SIM* input FLO file containing naturalized flows. *SIM* creates an output OUT file read by *TABLES* which includes the naturalized flows. The *SIM* input DAT file and *TABLES* input TIN file reproduced as Tables 6.5 and 6.6 are used in this example to develop the time series tabulations of Tables 6.8, 6.9, 6.18 and 6.19 and frequency metrics of Tables 6.10 and 6.11. The HIN file of Table 6.7 generates a DSS file with the flows read from a FLO file.

Table 6.4  
Quadrangle Areas

Cameron Gage on Little River			Easterly Gage on Navasota River		
Quadrangle Identifier	Watershed Area (sq miles)	Total Area Quadrangle (sq miles)	Quadrangle Identifier	Watershed Area (sq miles)	Total Area Quadrangle (sq miles)
710	1,896	4,092	611	925	4,050
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			

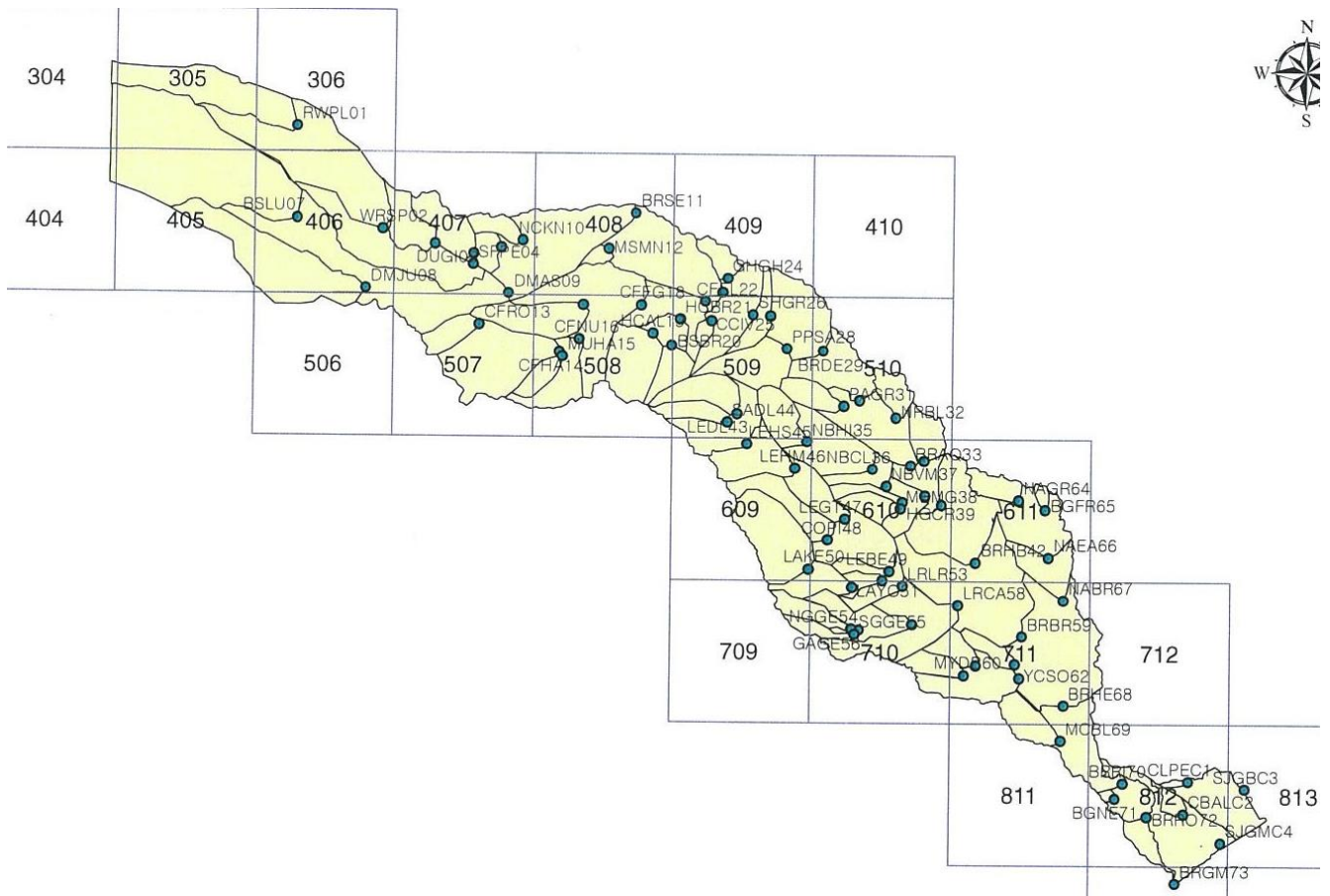


Figure 6.4 Brazos River Basin Quadrangles, Primary Control Points, and Watersheds

Table 6.5  
Program *SIM* Input DAT File Used to Create OUT File for Program *TABLES*

JD	58	1940	1	-1	
JO	-2				
CPLRCA58					NONE
CPNAEA66					NONE
WRLRCA58					
ED					

Table 6.6  
Program *TABLES* Input TIN File Used to Create Frequency and Time Series Tables

2FRE	1	2
2NAT	1	
ENDF		

Table 6.7  
Program *HYD* Input HIN File Used to Create DSS File of Known Naturalized Flows

JC	1940	58	1	2	6
CPLRCA58					
CPNAEA66					
ED					

### TCEQ WAM System Naturalized Flows

The January 1940 through December 1997 naturalized flows for control points LRCA58 and NAEA66 at the Cameron and Easterly gages from the TCEQ WAM System dataset for the Brazos River Basin are tabulated in Tables 6.8 and 6.9 and plotted in Figures 6.5 and 6.6.

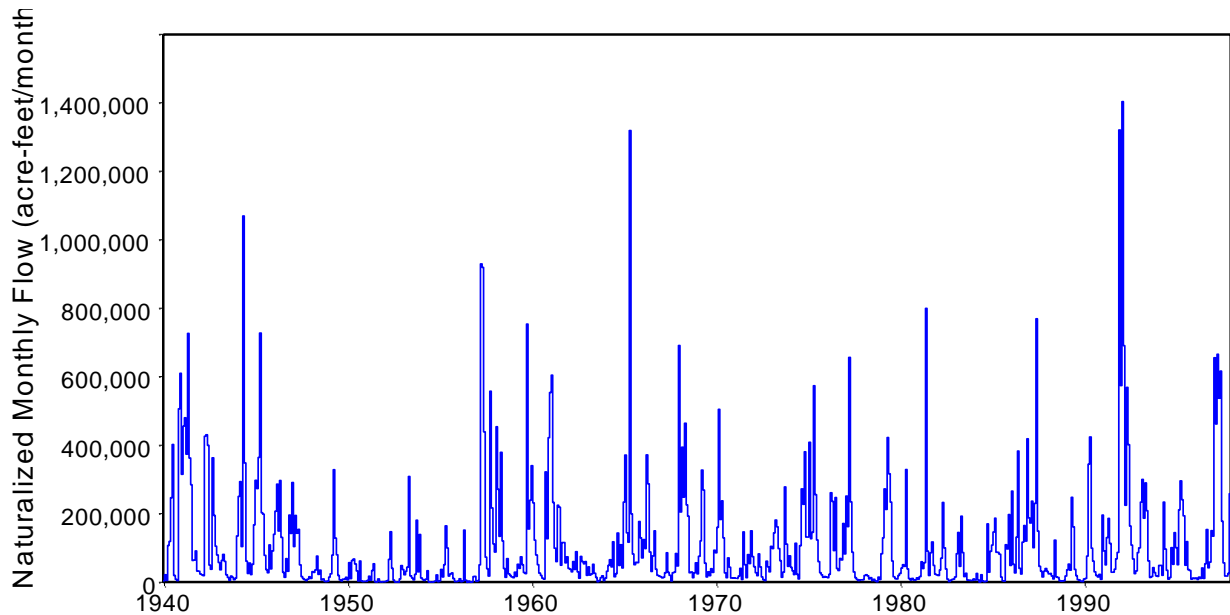


Figure 6.5 WAM System 1940-1997 Naturalized Flows at the Cameron Gage on the Little River

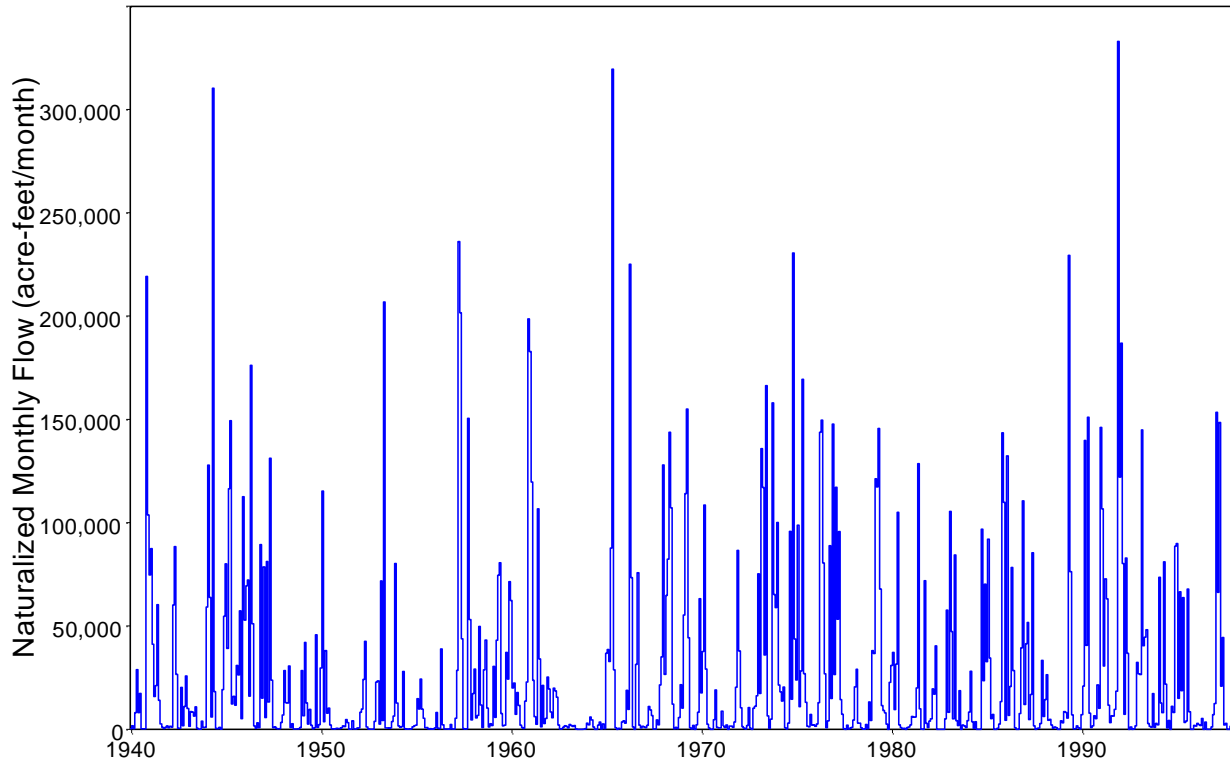


Figure 6.6 WAM System 1940-97 Naturalized Flows at the Easterly Gage on the Navasota River

The plots of Figures 6.5 and 6.6 were developed using HEC-DSSVue with a DSS file created with *HYD* with the HIN file of Table 6.7. The 2NAT tables of Tables 6.8 and 6.9 were created with *SIM* and *TABLES* with the input files of Tables 6.5 and 6.6. The frequency metrics for known flows in the first two columns of Tables 6.10 and 6.11 were also developed with *SIM* and *TABLES* with the DAT and TIN files of Tables 6.5 and 6.6. The original 1940-1997 naturalized flows from the WAM dataset are called the known flows in the following discussion.

#### Low, Medium, High, and Flood Flows

The following limits are adopted for defining low, medium, high, and flood flows in the calibration and extension computations. These flow zone limits are defined in Figure 6.1 and specified on the flow zone *FZ* record using the default FE(13) option 1.

##### Control Point LRCA58 at Cameron Gage on Little River

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

##### Control Point NAEA66 at Easterly Gage on Navasota River

HU	=	20% exceedance frequency known flow	=	40,602 acre-feet/month
FL	=	30% exceedance frequency known flow	=	21,528 acre-feet/month
MU and HL	=	50% exceedance frequency known flow	=	5,743 acre-feet/month
LU and ML	=	75% exceedance frequency known flow	=	848 acre-feet/month

**Table 6.8**  
**Original 1940-1997 Naturalized Flows in acre-feet at the Cameron Gage on the Little River**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	4226.	21590.	5258.	106875.	118827.	246700.	402103.	19420.	8136.	4495.	506043.	610025.	2053698.
1941	315015.	455249.	479749.	373647.	726451.	362613.	284318.	63419.	64427.	91154.	32427.	31703.	3280172.
1942	23611.	21123.	19061.	425969.	430471.	399415.	50025.	37408.	363203.	194891.	104993.	79515.	2149685.
1943	57420.	35888.	63316.	80835.	60426.	21544.	13364.	5496.	17900.	14417.	7410.	11746.	389762.
1944	135108.	250462.	293583.	104171.	1068994.	348162.	61100.	25487.	56027.	22390.	51862.	167741.	2585087.
1945	297407.	273083.	363821.	727424.	202570.	198540.	78128.	36705.	27622.	108972.	38913.	91310.	2444495.
1946	139675.	206939.	285995.	149245.	296669.	130473.	28745.	14295.	68529.	31980.	195864.	142339.	1690748.
1947	291011.	104021.	194624.	143003.	153937.	50414.	16068.	10291.	7176.	4705.	8829.	15755.	999834.
1948	10867.	30930.	28825.	35462.	76134.	22574.	34972.	6921.	9553.	2397.	1731.	2768.	263134.
1949	14724.	24366.	78939.	328272.	128540.	79661.	19280.	6422.	3333.	8832.	8073.	13895.	714337.
1950	6727.	56793.	10489.	63097.	67404.	53390.	32616.	3481.	61698.	3378.	1664.	2178.	362915.
1951	2612.	5157.	17554.	5356.	33662.	53473.	1469.	357.	9342.	1084.	813.	1269.	132148.
1952	1434.	2197.	4451.	66336.	147443.	40467.	6170.	631.	194.	42.	9515.	48595.	327475.
1953	36748.	21496.	31670.	43639.	308665.	18478.	11832.	6446.	22462.	180731.	30011.	139039.	851217.
1954	12248.	7277.	5001.	8669.	33502.	885.	383.	499.	1261.	3035.	21181.	1445.	95386.
1955	3872.	36918.	15379.	51025.	164383.	99776.	17921.	23814.	27151.	10262.	1651.	2016.	454168.
1956	2934.	9845.	1134.	2816.	152079.	5674.	0.	2835.	0.	965.	16402.	16922.	211606.
1957	2608.	4490.	50463.	929072.	918874.	438716.	73019.	39289.	18151.	557391.	216694.	111667.	3360434.
1958	88002.	453666.	271342.	134038.	378932.	120411.	39544.	14005.	68454.	24501.	19316.	15032.	1627243.
1959	13153.	29231.	17095.	52065.	40144.	73992.	51048.	28166.	24919.	753704.	155207.	238967.	1477691.
1960	340219.	231706.	122548.	79105.	51140.	26225.	19517.	11294.	8639.	322054.	127079.	421910.	1761436.
1961	553706.	604542.	232899.	98858.	60088.	224407.	218538.	49457.	115461.	115421.	56456.	73767.	2403600.
1962	40457.	37607.	29942.	60340.	37024.	88833.	30018.	11344.	74927.	59877.	53625.	60050.	584044.
1963	19814.	44799.	20596.	23763.	51968.	25929.	13560.	1460.	4582.	13295.	18464.	4744.	242974.
1964	11307.	31646.	48923.	65542.	44837.	117572.	15580.	24676.	143601.	48880.	109312.	41258.	703134.
1965	233735.	370929.	143957.	116742.	1318816.	199502.	82164.	51249.	57907.	57116.	177225.	129637.	2938979.
1966	70898.	124114.	97968.	371795.	286922.	87782.	31012.	76562.	150089.	37779.	20018.	17768.	1372707.
1967	15648.	12770.	13966.	27670.	85515.	28518.	19777.	3479.	27728.	29354.	83485.	47114.	395024.
1968	691195.	205119.	393816.	247919.	463806.	225958.	192749.	27593.	29522.	13098.	26881.	56212.	2573868.
1969	24533.	75747.	120277.	327202.	268971.	55233.	15243.	30381.	18782.	39111.	28597.	93104.	1097181.
1970	85925.	160015.	504530.	182973.	237648.	129579.	26751.	13200.	70584.	43533.	12277.	12767.	1479782.
1971	11879.	11593.	12004.	17895.	40452.	7665.	146759.	51247.	12873.	80498.	54209.	149841.	596915.
1972	74681.	45317.	27688.	18960.	82310.	44853.	14989.	7141.	4276.	61086.	44521.	30031.	455853.
1973	104438.	98034.	143990.	181291.	161860.	98294.	62933.	14159.	29256.	278181.	110709.	46228.	1329373.
1974	76926.	43133.	33649.	22309.	113400.	22808.	9571.	106606.	272382.	227246.	380376.	131691.	1440097.
1975	131636.	408286.	126988.	145374.	573701.	255471.	123061.	60054.	27287.	21599.	14049.	16227.	1903733.
1976	14865.	13265.	22672.	260733.	235938.	92373.	247140.	39966.	34043.	69352.	64923.	171137.	1266407.
1977	82730.	251201.	161950.	656109.	234136.	87293.	29728.	13090.	7981.	4645.	6539.	6462.	1541864.
1978	7337.	19546.	21682.	18293.	9536.	13266.	4802.	8269.	3698.	1519.	14720.	7501.	130169.
1979	83145.	129735.	272084.	212412.	422369.	316696.	233681.	61632.	15847.	10211.	9322.	19413.	1786547.
1980	25594.	40885.	50864.	46476.	328986.	38696.	10670.	6084.	10707.	5963.	6568.	12796.	584289.
1981	8964.	16086.	59378.	39855.	57057.	799417.	90423.	19309.	85928.	117109.	48980.	23149.	1365655.
1982	20992.	19687.	35745.	69523.	232452.	100366.	38295.	8665.	2009.	5190.	7951.	8709.	549584.
1983	15134.	83314.	145185.	46042.	192718.	86093.	16414.	26040.	6341.	5588.	4951.	5089.	632909.
1984	9168.	6405.	25218.	6843.	207.	21514.	3465.	1259.	2302.	170360.	29158.	89979.	365878.
1985	108080.	145987.	186568.	87601.	86664.	81531.	14701.	3966.	3075.	109496.	96981.	197214.	1121864.
1986	49014.	265813.	52271.	27167.	131271.	382704.	40139.	23807.	116569.	165242.	119916.	418349.	1792262.
1987	187741.	172902.	236611.	100795.	229780.	769125.	148625.	46189.	31538.	15023.	31699.	39841.	2009869.
1988	31269.	24431.	25216.	18001.	9350.	122843.	15192.	13400.	4700.	2730.	3617.	4298.	275047.
1989	17931.	36193.	52408.	34837.	247694.	161443.	37365.	19098.	7286.	6161.	2531.	2071.	625018.
1990	9514.	10753.	76108.	344155.	423858.	98865.	61149.	30140.	19711.	15035.	22719.	8341.	1120348.
1991	195638.	91220.	50450.	130030.	186205.	112987.	28856.	28875.	37788.	68174.	87033.	1320477.	2337733.
1992	574007.	1403136.	690408.	224458.	568694.	401559.	163609.	107953.	67406.	24855.	32663.	86273.	4345021.
1993	100136.	233876.	299945.	186726.	290048.	208711.	62120.	13708.	16249.	42243.	28287.	18564.	1500613.
1994	16754.	48847.	49040.	19774.	233470.	96358.	34327.	8664.	13725.	100557.	52099.	144553.	818168.
1995	100503.	51057.	211495.	295836.	240525.	193678.	49472.	118107.	36377.	33867.	8819.	11828.	1351564.
1996	10371.	12165.	7739.	14624.	11049.	41477.	11180.	53649.	153452.	42102.	58669.	150299.	566776.
1997	134515.	655338.	461944.	665585.	536956.	616065.	177556.	56231.	17994.	17905.	25341.	258527.	3623957.
MEAN	99134.	142895.	129422.	160769.	246475.	159432.	64883.	27472.	44865.	77600.	60506.	104847.	1318302.

**Table 6.9**  
**Original 1940-1997 Naturalized Flows in acre-feet at the Easterly Gage on the Navasota River**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	245.	1750.	269.	8032.	28826.	8044.	17329.	217.	223.	204.	219220.	103682.	388041.
1941	74737.	87468.	41141.	15872.	21081.	60311.	13978.	2587.	932.	364.	912.	1611.	320994.
1942	733.	1423.	980.	60156.	88432.	26542.	493.	500.	20236.	1677.	11032.	25803.	238007.
1943	10095.	1414.	8522.	8314.	6398.	10856.	447.	33.	15.	3883.	843.	953.	51773.
1944	59128.	127872.	63791.	5934.	310223.	18264.	402.	278.	926.	82.	19208.	54692.	660800.
1945	80066.	39118.	116438.	149354.	12265.	15963.	11605.	30843.	26302.	57325.	5169.	112543.	656991.
1946	52788.	69403.	72201.	16019.	176110.	51090.	1657.	472.	3095.	727.	89358.	15060.	547980.
1947	78550.	5664.	81231.	13247.	131198.	23801.	744.	1163.	389.	197.	311.	3324.	339819.
1948	6919.	28438.	12906.	12708.	30642.	823.	2636.	106.	130.	98.	185.	848.	96439.
1949	28418.	6587.	41997.	12790.	2487.	9575.	1879.	261.	743.	45742.	925.	2260.	153664.
1950	29608.	115303.	3602.	38051.	7801.	10255.	2043.	250.	183.	153.	465.	269.	207983.
1951	375.	728.	1597.	1231.	4704.	3192.	82.	40.	4123.	143.	168.	568.	16951.
1952	634.	8185.	9823.	24151.	42572.	1134.	160.	75.	62.	36.	3786.	22833.	113451.
1953	23409.	2519.	71805.	4235.	206764.	634.	699.	500.	619.	3750.	6401.	80262.	401597.
1954	12731.	1596.	935.	1264.	27933.	264.	78.	93.	83.	228.	1171.	1704.	48080.
1955	2009.	14805.	9777.	24300.	9706.	5329.	741.	860.	103.	327.	46.	141.	68144.
1956	615.	8081.	454.	331.	38821.	2164.	116.	103.	121.	51.	2313.	137.	53307.
1957	129.	5292.	28508.	236075.	201624.	43797.	288.	120.	241.	150502.	53077.	4511.	724164.
1958	17259.	29155.	5484.	6709.	49756.	11706.	832.	28787.	43187.	10257.	1095.	2676.	206903.
1959	1830.	30473.	5743.	43115.	74561.	80563.	7556.	1584.	1967.	37200.	24305.	71407.	380304.
1960	62337.	19961.	22347.	7280.	17775.	11523.	2013.	835.	416.	13588.	22866.	198632.	379573.
1961	182840.	119656.	23633.	6137.	2413.	106683.	34014.	1202.	21252.	2770.	5267.	25282.	531149.
1962	19498.	8355.	5592.	19925.	18619.	15472.	2084.	113.	265.	1024.	1709.	1359.	94015.
1963	624.	2324.	1760.	1401.	1763.	168.	0.	0.	0.	0.	61.	276.	8377.
1964	2899.	2151.	5893.	4491.	1113.	0.	0.	2006.	3486.	123.	2570.	297.	25029.
1965	36736.	38590.	32766.	87704.	319449.	28796.	769.	0.	445.	161.	3527.	4107.	553050.
1966	2946.	18830.	9578.	225038.	73405.	1125.	0.	31401.	75732.	1950.	627.	1437.	442069.
1967	1133.	771.	1859.	11022.	9362.	6602.	155.	131.	4531.	2190.	21441.	34990.	94187.
1968	127908.	26576.	64778.	82370.	143710.	107227.	12140.	257.	903.	312.	5676.	21601.	593458.
1969	10205.	55265.	114043.	154957.	44303.	710.	127.	1928.	0.	2111.	8198.	63235.	455082.
1970	17611.	37658.	108481.	29095.	2419.	594.	0.	0.	4652.	19047.	950.	660.	221167.
1971	694.	8735.	1535.	875.	2036.	0.	1520.	1543.	952.	3510.	20354.	86519.	128273.
1972	37902.	10412.	1277.	553.	136.	1814.	10458.	512.	0.	10129.	11078.	16190.	100461.
1973	75198.	17350.	135856.	117051.	35950.	166295.	6452.	422.	4860.	157953.	65192.	58933.	841512.
1974	100118.	21428.	18152.	13656.	20419.	774.	153.	2963.	95798.	14508.	230522.	43720.	562211.
1975	23859.	98785.	10970.	28201.	169372.	26919.	13068.	1422.	1196.	7120.	2012.	2146.	385070.
1976	1436.	2600.	12839.	143733.	149635.	80534.	26836.	729.	4059.	88808.	14848.	147673.	673730.
1977	26511.	117098.	53282.	95680.	14400.	7237.	344.	0.	2001.	130.	610.	940.	318233.
1978	4395.	20470.	28999.	2939.	2902.	781.	120.	10.	2342.	332.	13229.	4281.	80800.
1979	38040.	36671.	121285.	117328.	145535.	67852.	11447.	9122.	7962.	2466.	0.	22693.	580401.
1980	30832.	37161.	9519.	31464.	105019.	2130.	805.	179.	451.	0.	791.	1091.	219442.
1981	2062.	6169.	5805.	19994.	128546.	9897.	21.	0.	0.	71874.	2870.	866.	254053.
1982	3870.	5078.	19531.	17028.	40359.	0.	0.	0.	0.	0.	5015.	57626.	148507.
1983	8178.	105404.	47336.	5036.	84404.	4141.	1822.	18690.	0.	2083.	1594.	870.	279558.
1984	4145.	8320.	28036.	3614.	373.	3657.	0.	0.	0.	96841.	23480.	70245.	238711.
1985	32700.	91986.	34484.	5128.	7165.	0.	0.	459.	2514.	13371.	143444.	109856.	441107.
1986	4314.	132331.	6738.	20641.	78306.	28391.	739.	0.	0.	7565.	39413.	110537.	428975.
1987	11988.	41387.	51649.	4665.	16857.	85426.	1611.	0.	433.	598.	2759.	33362.	250735.
1988	6187.	14328.	26390.	4357.	4761.	2053.	492.	1056.	771.	0.	0.	4062.	64457.
1989	3161.	8529.	8083.	5361.	229403.	76305.	6972.	200.	328.	1640.	715.	130.	340827.
1990	7091.	20819.	139775.	40649.	151030.	7744.	839.	1634.	6513.	5148.	21510.	10121.	412873.
1991	146114.	106671.	30613.	72759.	63073.	11635.	3177.	6555.	6327.	9624.	18375.	332958.	807881.
1992	122024.	186852.	80245.	7239.	82824.	36796.	0.	1134.	0.	211.	1632.	32342.	551299.
1993	26834.	26438.	144903.	40412.	44533.	48182.	2795.	1373.	983.	17240.	904.	2869.	357466.
1994	2171.	73596.	12657.	7993.	80999.	21869.	633.	4249.	0.	11080.	8157.	88602.	312006.
1995	89897.	14974.	66527.	18677.	63691.	3329.	4031.	67847.	8462.	0.	0.	1863.	339298.
1996	1548.	2839.	2214.	1763.	5213.	0.	3497.	0.	0.	0.	1095.	7036.	25205.
1997	12399.	153388.	66259.	148472.	20820.	44430.	2107.	2838.	0.	0.	1408.	41771.	493892.
MEAN	30495.	39401.	36774.	39182.	64577.	26208.	3877.	3960.	6230.	15146.	19722.	37008.	322578.

Table 6.10  
Flow Frequency Metrics in acre-feet/month for Calibration and Extension  
for Control Point LRCA58 at Cameron Gage on the Little River

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2012	Extension 1998-2012
Mean	109,858	129,565	109,710	112,853	124,433
Std Dev	170,466	226,687	165,869	180,962	216,985
Minimum	0.0	132.8	0.0	0.0	0.0
99.5%	200.2	373.6	183.2	47.9	0.0
99%	494.4	481.2	1,047	321.0	45.9
98%	1249	569.8	1,240	1,026	644
95%	2,706	900.2	3,107	2,157	1,216
90%	5,440	1,127	4,245	4,779	4,245
85%	8,667	1,312	8,237	8,348	7,615
80%	11,904	1,690	10,611	11,394	8,881
75%	15,032	2,606	16,369	15,023	14,750
70%	19,041	3,310	18,193	18,475	16,369
60%	28,988	6,238	26,123	28,550	26,123
50%	44,799	18,830	43,135	43,639	42,996
40%	65,294	34,370	62,384	61,886	53,369
30%	104,549	109,140	108,289	100,514	74,181
25%	130,473	167,350	135,734	129,637	107,242
20%	165,070	233,080	173,693	170,982	202,888
15%	226,731	294,653	209,631	233,713	282,527
10%	290,433	459,524	317,261	296,964	362,168
5%	426,869	617,683	429,632	432,120	560,662
2%	667,571	926,244	728,500	726,918	1,062,734
1%	804,195	1,030,350	810,381	960,588	1,173,856
0.5%	1,198,902	1,272,942	1,001,182	1,210,635	1,243,912
Maximum	1,403,136	1,368,058	1,075,991	1,403,136	1,243,912

Tables 6.10 and 6.11 show the mean, standard deviation, and monthly flow volumes associated with specified exceedance frequencies for the various stages of the parameter calibration and flow extension process. The flow quantities are in units of acre-feet/month. The columns of Tables 6.10 and 6.11 are defined as follows.

- Column 1: Percentage of months during which the flow volume is equaled or exceeded.
- Column 2: Known flows tabulated in Tables 6.8 and 6.9 and plotted in Figures 6.5 and 6.6.
- Column 3: Flows computed by the flow model at completion of the level 1 calibration.
- Column 4: Flows computed by the final model at completion of the level 2 calibration.
- Column 5: Known 1940-1997 flows and final 1998-2012 computed flows.
- Column 6: Final 1998-2012 computed flows.

Table 6.11  
Flow Frequency Metrics in acre-feet/month for Calibration and Extension  
for Control Point NAEA66 at Easterly Gage on the Navasota River

1	2	3	4	5	6
	Original Known 1940-1997	Level 1 Computed 1940-1997	Final Computed 1940-1997	Combined 1940-2012	Extension 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
99.5%	0.0	0.0	0.0	0.0	0.0
99%	0.0	0.0	0.0	0.0	0.0
98%	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

### Level 1 Calibration

Calibration consists of determining the values for the parameters entered on *FE*, *FZ*, *FR*, *UB*, *BM*, *B4*, *XP*, and *X4* records in the *HYD* input HIN file for the flow extension model. Level 1 calibration consists of determining the quantities on the *BM*, *B4*, *XP*, *X4*, *FZ*, and *UB* records. Level 2 calibration consists of determining values for parameters on the *FR*, *FX*, and *UB* records. The *UB* record contains parameters from both the level 1 and level 2 calibration.

The *HYD* input HIN file for the level 1 calibration is reproduced as Table 6.12. Two sets of model parameters are developed based on defining flow zones as outlined in Figure 6.1 and

Table 6.1. The two *FE* records calibrate parameters for non-flood flows and flood flows. The following objective function OF is adopted for calibrating parameters for the non-flood flow model.

$$\text{OF} = 1.0 \times Z1 + 1.0 \times Z2 + 1.0 \times Z3 + 3.0 \times Z5 + 3.0 \times Z6 + 3.0 \times Z7 \\ + 10.0 \times Z9 + 10.0 \times Z10 + 10.0 \times Z11 + 10.0 \times Z13 + 10.0 \times Z14 + 10.0 \times Z15$$

The following objective function is adopted for calibrating parameters for the flood flow model.

$$\text{OF} = 1.0 \times Z4 + 3.0 \times Z8 + 10.0 \times Z12 + 10.0 \times Z16$$

Table 6.12  
Program *HYD* Input HIN File for Level 1 Parameter Calibration

```
** HYD File Cal.HIN for Flow Extension Calibration for Two Control Points
**
JC 1940 58 1 2 0
CPLRCA58
CPNAEA66
**      1      2      3      4      5      6      7      8
**34567890123456789012345678901234567890123456789012345678901234
**      !      !      !      !      !      !      !      !      !      !      !      !      !      !      !      !
**
** Calibration for All Flows Except Flood Flows for LRCA58
FELRCA58      1940 1997 2 9      2 1 5440. -1.0
FN Non-Flood
QD 4 7 710 610 609 711 709 509 508
QA      1896. 1470. 2129. 77. 324. 1063. 115.
FP 1.0 1.0 1.0 3.0 3.0 3.0 10. 10. 10. 10. 10. 10. 2
FZ      11904.0 28988.2 104549. 65294.4
** Calibration for Flood Flows
FELRCA58      1940 1997 2 10      1
FN Flood
FP      1.0 3.0 10. 10. 2
**
** Calibration for All Flows Except Flood Flows for NAEA66
FENAEA66      1940 1997 2 9      1 0 0. -1.0
FN Non-Flood
QD 1 611
QA 925.
FP 1.0 1.0 1.0 3.0 3.0 3.0 10. 10. 10. 10. 10. 10. 1
FZ      848.0 5743.0 40601.6 21528.2
** Calibration for Flood Flows
FENAEA66      1940 1997 2 10      1
FN Flood
FP      1.0 3.0 10. 10. 1
ED
```

Execution of *HYD* with the input HIN file of Table 6.12 results in the HMS and HOT files of Tables 13 and 14. The validity and accuracy of the calibration is tested by comparing 1940-1997 computed flows with the corresponding 1940-1997 known flows from the WAM dataset. The frequency metrics in Tables 10 and 11 were developed from *HYD* generated FLO files using *SIM* and *TABLES* with the DAT and TIN files of Tables 8 and 9. The frequency metrics for the known naturalized flows are shown in column 2. The flows computed with the model resulting from the level 1 calibration are summarized in column 3 of Tables 10 and 11.

All of the plots for the example were made with HEC-DSSVue from DSS files created with *HYD*. The monthly flows computed using the parameters from the level 1 calibration are plotted in Figures 6.7 and 6.9 along with the known flows for comparison. The Figures 6.7 and 6.9 graphs correspond to columns 2 and 3 of Tables 6.10 and 6.11.

Figures 6.8 and 6.10 are plots of 12-month moving averages. The flow volume plotted for each month is the average monthly volume during a year consisting of that month and the next 11 months. Annual moving averages of computed versus known flows are compared.

The steps in the automated optimization based level 1 parameter calibration process can be tracked through the *HYD* message HMS file reproduced as Table 6.13. Non-flood (low and normal flows) and flood (higher flows) models are calibrated for control points LRCA58 and NAEA66 as outlined in the HMS file.

Table 6.13  
Program *HYD* Message HMS File for Level 1 Parameter Calibration

```

WRAP-HYD MESSAGE FILE

*** Starting to read file Cal.HIN
*** JC record was read.
*** Starting to read CP records.
*** Finished reading CP records.
*** Finished reading file Cal.HIN
*****
Record counts for selected HIN file record types.
    2 control point CP records
    2 control points with streamflows read as input
    4 flow extension FE records
*****
*** Starting to read IN and/or EV records in JC(1),JC(2)=2 format.
*** Reordering IN records and multiplying by factors on CP records.
*** Finished reading IN records from FLO file in JC(1)=2 format.
*** Finished reading IN and/or EV records.
*** Starting hydrologic period-of-analysis extension routine.

*** FE record was read for control point LRCA58.
*** QD record was read for control point LRCA58.
*** QA record was read for control point LRCA58.
*** FP record was read for control point LRCA58.
*** FZ record was read for control point LRCA58.
*** Starting to read PPP and/or EEE files.
*** Finished reading Precipitation.PPP file.
*** Finished reading Evaporation.EEE file.

Number of months (1940-1997)      =      696
Mean Known Flow (acre-feet/month)=  109858.4
Flow/Precipitation Ratio          =    0.11286
Mean Precipitation (ac-ft/month) =  973371.9
Mean Evaporation (ac-ft/month)   = 1860045.6
Watershed Area (square miles)    =    7074.0
Mean Precipitation (inches/year) =    30.96
Mean Evaporation (inches/year)   =    59.16

*** Starting FE record parameter optimization Non-Flood

Initial Enumeration X(1,j) = 0.60 1.00 0.40 1.00 1.00
Initial Enumeration X(2,j) = 1.00 1.00 0.40 1.00 1.00

```

Initial Enumeration X(3,j) = 1.00 1.00 0.00 0.50 1.00  
 Initial Enumeration X(4,j) = 1.00 1.00 0.40 1.00 1.00  
 Initial Enumeration X(5,j) = 1.00 1.00 0.40 1.00 1.00  
 Initial Enumeration X(6,j) = 1.00 1.00 0.40 1.00 1.00  
 Initial Enumeration X(7,j) = 1.00 1.00 0.40 1.00 1.00  
 U(1) = 1.00 U(2) = 1.00 BX = 1.00  
 Objective Function OF = 2741226.50  
 Refined Enumeration X(1,j) = 0.54 1.00 0.34 0.94 1.00  
 Refined Enumeration X(2,j) = 1.01 1.00 0.40 1.00 1.00  
 Refined Enumeration X(3,j) = 1.00 1.00 0.00 0.50 1.00  
 Refined Enumeration X(4,j) = 1.00 1.00 0.40 1.00 1.00  
 Refined Enumeration X(5,j) = 1.00 1.00 0.40 1.00 1.00  
 Refined Enumeration X(6,j) = 1.00 1.00 0.40 1.00 1.00  
 Refined Enumeration X(7,j) = 1.00 1.00 0.40 1.00 1.00  
 U(1) = 0.94 U(2) = 0.96 BX = 1.00  
 Objective Function OF = 2211141.00

Flow zones	Low	Medium	High	Flood
Lower limits ML, HL, FL (ac-ft/month) =	0.	11904.	28988.	65294.
Upper limits LU, MU, HU (ac-ft/month) =	11904.	28988.	104549.	
Months of low, medium, high, flood flows =	140	139	209	278
Mean of known flows (acre-feet/month) =	5675.	19546.	58254.	239917.

Mean of Initial Computed Flows (ac-ft/m) = 17550.1  
 Mean of Initial B(m) Flows (ac-ft/month) = 3410.4

#### Initial Parameter Calibration Results Prior to Gradient Search: Non-Flood

Objective function OF = 2211141.000  
 Number of times objective function computed = 2393181  
 Z1,Z5,Z9,Z13 = 29946.4 5580.5 168100.0 2363.44  
 Z2,Z6,Z10,Z14 = 11821.5 7696.1 11236.0 5115.89  
 Z3,Z7,Z11,Z15 = 8554.7 7602.5 16900.0 6102.81  
 Z4,Z8,Z12,Z16 = 13690.1 7635.4 45796.0 7286.60  
 B(m) = 2947.7 5440.0 5440.0 5440.0 5440.0 5440.0  
           2714.8 1173.5 1473.5 1456.2 2001.2 1957.8  
 X(1,j) = 0.540000 1.000000 0.340000 0.940000 1.000000  
 X(2,j) = 1.010000 1.000000 0.400000 1.000000 1.000000  
 X(3,j) = 1.000000 1.000000 0.000000 0.500000 1.000000  
 X(4,j) = 1.000000 1.000000 0.400000 1.000000 1.000000  
 X(5,j) = 1.000000 1.000000 0.400000 1.000000 1.000000  
 X(6,j) = 1.000000 1.000000 0.400000 1.000000 1.000000  
 X(7,j) = 1.000000 1.000000 0.400000 1.000000 1.000000  
 U(1) = 0.940 U(2) = 0.960 DX = 1.0000 BX = 1.00000

Results After Gradient Search But Before Final DX Calibration: DX = 1.0000  
 Number of times drought index activated = 357  
 Number of months with known and computed flows below 0.0 ac-ft = 2 0  
 Number of objective function evaluations = 2395205  
 Objective Function OF = 513884.188  
 Z1,Z5,Z9,Z13 = 26712.3 5415.3 33124.0 53.39  
 Z2,Z6,Z10,Z14 = 7755.0 6153.3 484.0 2640.48  
 Z3,Z7,Z11,Z15 = 5797.0 5085.5 1936.0 4127.91  
 Z4,Z8,Z12,Z16 = 0.0 0.0 0.0 0.00

#### Final Parameter Calibration Results: Non-Flood

Period-of-analysis is 1940 through 1997  
 Means of known and computed flows = 109858.4 23413.4 acre-feet/month

Limits based on known flows:  
 Means of known and computed low flows = 5674.6 6576.8 acre-feet/month  
 Means of known and computed medium flows = 19546.4 10036.5 acre-feet/month  
 Means of known and computed high flows = 58254.1 21245.1 acre-feet/month

Means of known and computed flood flows = 239917.4 41551.7 acre-feet/month  
 Number of months of low, medium, high, and flood flows = 140 139 209 278

Limits based on computed flows:

Means of known and computed low flows = 32533.8 2971.4 acre-feet/month  
 Means of known and computed medium flows = 77388.8 20399.3 acre-feet/month  
 Means of known and computed high flows = 206187.2 48875.8 acre-feet/month  
 Means of known and computed flood flows = 469316.6 80516.5 acre-feet/month  
 Number of months of low, medium, high, and flood flows = 316 122 254 49

Number of times drought index activated = 185

Number of months with known and computed flows below 0.0 ac-ft = 2 0

Number of search cycles and objective function evaluations = 8 and 2401208

Objective Function OF = 485481.750

Z1,Z5,Z9,Z13 = 26715.9 4720.7 30976.0 252.76  
 Z2,Z6,Z10,Z14 = 7359.0 5748.1 289.0 2367.14  
 Z3,Z7,Z11,Z15 = 5681.2 4953.1 2025.0 4036.09  
 Z4,Z8,Z12,Z16 = 13476.3 6222.0 52441.0 6836.12

Non-Flood Multiplier Factor U(1) = 0.864575  
 Exponent U(2) = 0.824727  
 Base Flow Factor BX = 0.960000  
 Drought Index Factor DX = 1.571017

Final Parameters in Input Record Format LRCA58 Non-Flood

QD	7	710	610	609	711	709	509	508
QA	0	1896.00	1470.00	2129.00	77.00	324.00	1063.00	115.00
BM		2947.67	5440.00	5440.00	5440.00	5440.00	5440.00	2714.83 1173.50 1473.50 1456.17 2001.17 1957.83
XP	710	0.28870958	0.85737497	0.32454535	0.95933706	0.94999999		
XP	610	0.71711218	0.94999999	0.40000001	0.95000011	1.00000000		
XP	609	0.81450635	1.00000000	0.00002257	0.55124998	1.00000000		
XP	711	0.94999999	1.00000000	0.41894999	1.00000000	0.97999990		
XP	709	0.85737509	0.94999999	0.38000000	0.94999999	0.97999990		
XP	509	0.94762510	1.00000000	0.38000000	0.98000002	1.00000000		
XP	508	1.00000000	1.00000000	0.40000001	1.00000000	0.97999990		

\*\*\* FE record was read for control point LRCA58.  
 \*\*\* FP record was read for control point LRCA58.  
 \*\*\* Starting FE record parameter optimization Flood

Initial Enumeration X(1,j) = 0.60 1.00 0.40 1.00 1.00  
 Initial Enumeration X(2,j) = 1.00 1.00 0.40 1.00 1.00  
 Initial Enumeration X(3,j) = 1.00 1.00 0.00 0.50 1.00  
 Initial Enumeration X(4,j) = 1.00 1.00 0.40 1.00 1.00  
 Initial Enumeration X(5,j) = 1.00 1.00 0.40 1.00 1.00  
 Initial Enumeration X(6,j) = 1.00 1.00 0.40 1.00 1.00  
 Initial Enumeration X(7,j) = 1.00 1.00 0.40 1.00 1.00  
 U(1) = 0.70 U(2) = 1.20 BX = 1.00  
 Objective Function OF = 496792.91  
 Refined Enumeration X(1,j) = 0.54 1.00 0.34 0.95 1.00  
 Refined Enumeration X(2,j) = 1.01 1.00 0.40 1.00 1.00  
 Refined Enumeration X(3,j) = 1.00 1.00 0.00 0.50 1.00  
 Refined Enumeration X(4,j) = 1.00 1.00 0.40 1.00 1.00  
 Refined Enumeration X(5,j) = 1.00 1.00 0.40 1.00 1.00  
 Refined Enumeration X(6,j) = 1.00 1.00 0.40 1.00 1.00  
 Refined Enumeration X(7,j) = 1.00 1.00 0.40 1.00 1.00  
 U(1) = 0.64 U(2) = 1.17 BX = 1.00  
 Objective Function OF = 350644.84

Flow zones	Low	Medium	High	Flood
Lower limits ML, HL, FL (ac-ft/month) =	0.	11904.	28988.	65294.

Upper limits LU, MU, HU (ac-ft/month) = 11904. 28988. 104549.  
Months of low, medium, high, flood flows = 140 139 209 278  
Mean of known flows (acre-feet/month) = 5675. 19546. 58254. 239917.

Mean of Initial Computed Flows (ac-ft/m) = 103686.0  
Mean of Initial B(m) Flows (ac-ft/month) = 5177.5

#### Initial Parameter Calibration Results Prior to Gradient Search: Flood

Objective function OF = 350644.844  
Number of times objective function computed = 2469621  
Z1,Z5,Z9,Z13 = 427563.2 4771.9 28224.0 7013.59  
Z2,Z6,Z10,Z14 = 133145.5 5947.7 961.0 0.54  
Z3,Z7,Z11,Z15 = 57784.7 5128.9 289.0 13.16  
Z4,Z8,Z12,Z16 = 27645.3 5493.3 30625.0 26.97  
B(m) = 2947.7 5895.2 5678.7 9367.2 16217.7 11247.0  
2714.8 1173.5 1473.5 1456.2 2001.2 1957.8  
X(1,j) = 0.540000 1.000000 0.340000 0.950000 1.000000  
X(2,j) = 1.010000 1.000000 0.400000 1.000000 1.000000  
X(3,j) = 1.000000 1.000000 0.000000 0.500000 1.000000  
X(4,j) = 1.000000 1.000000 0.400000 1.000000 1.000000  
X(5,j) = 1.000000 1.000000 0.400000 1.000000 1.000000  
X(6,j) = 1.000000 1.000000 0.400000 1.000000 1.000000  
X(7,j) = 1.000000 1.000000 0.400000 1.000000 1.000000  
U(1) = 0.640 U(2) = 1.170 DX = 1.5710 BX = 1.00000

#### Final Parameter Calibration Results: Flood

Period-of-analysis is 1940 through 1997  
Means of known and computed flows = 109858.4 129558.1 acre-feet/month

#### Limits based on known flows:

Means of known and computed low flows = 5674.6 12739.2 acre-feet/month  
Means of known and computed medium flows = 19546.4 31593.8 acre-feet/month  
Means of known and computed high flows = 58254.1 86445.2 acre-feet/month  
Means of known and computed flood flows = 239917.4 269567.1 acre-feet/month  
Number of months of low, medium, high, and flood flows = 140 139 209 278

#### Limits based on computed flows:

Means of known and computed low flows = 28232.8 2893.1 acre-feet/month  
Means of known and computed medium flows = 72192.3 19199.1 acre-feet/month  
Means of known and computed high flows = 105636.7 54887.1 acre-feet/month  
Means of known and computed flood flows = 227123.1 348262.8 acre-feet/month  
Number of months of low, medium, high, and flood flows = 303 94 86 245

Number of times drought index activated = 185  
Number of months with known and computed flows below 0.0 ac-ft = 2 0

Number of search cycles and objective function evaluations = 27 and 2475770  
Objective Function OF = 32671.750  
Z1,Z5,Z9,Z13 = 362529.3 4971.0 26569.0 15498.99  
Z2,Z6,Z10,Z14 = 168000.7 6431.0 2025.0 3798.85  
Z3,Z7,Z11,Z15 = 50769.0 5696.6 15129.0 2341.93  
Z4,Z8,Z12,Z16 = 8868.1 3795.5 1089.0 152.73

Flood Multiplier Factor U(1) = 0.353111  
Exponent U(2) = 1.100486  
Base Flow Factor BX = 1.000000  
Drought Index Factor DX = 1.571017

#### Final Parameters in Input Record Format LRCA58 Flood

QD 7 710 610 609 711 709 509 508  
QA 0 1896.00 1470.00 2129.00 77.00 324.00 1063.00 115.00

B4	2407.67	3207.94	3825.31	1953.13	8200.30	6744.71	1989.83	901.83	496.75	994.00	646.33	731.61
X4	710	0.38423160	1.00000000	0.32385236	0.90250009	1.00000000						
X4	610	0.78945827	0.98973340	0.40000001	0.98000002	1.00000000						
X4	609	0.95141560	1.00000000	0.00016040	0.55786967	0.97854763						
X4	711	1.00000000	0.97941959	0.40080041	0.98000002	1.00000000						
X4	709	0.79017901	0.94999999	0.36761713	0.95570862	1.00000000						
X4	509	1.00000000	1.00000000	0.42000002	0.88710600	1.00000000						
X4	508	0.86166883	0.94999999	0.40000001	1.00000012	1.00000000						

\*\*\* FE record was read for control point NAEA66.  
 \*\*\* QD record was read for control point NAEA66.  
 \*\*\* QA record was read for control point NAEA66.  
 \*\*\* FP record was read for control point NAEA66.  
 \*\*\* FZ record was read for control point NAEA66.  
 \*\*\* Starting to read PPP and/or EEE files.  
 \*\*\* Finished reading Precipitation.PPP file.  
 \*\*\* Finished reading Evaporation.EEE file.

Number of months (1940-1997)	=	696
Mean Known Flow (acre-feet/month)	=	26881.5
Flow/Precipitation Ratio	=	0.17126
Mean Precipitation (ac-ft/month)	=	156964.4
Mean Evaporation (ac-ft/month)	=	241096.8
Watershed Area (square miles)	=	925.0
Mean Precipitation (inches/year)	=	38.18
Mean Evaporation (inches/year)	=	58.65

\*\*\* Starting FE record parameter optimization Non-Flood

Initial Enumeration X(1,j) = 0.90 1.00 0.10 0.90 1.00  
 U(1) = 0.30 U(2) = 1.00 BX = 1.00  
 Objective Function OF = 396886.22  
 Refined Enumeration X(1,j) = 0.91 1.00 0.07 0.95 1.00  
 U(1) = 0.24 U(2) = 1.06 BX = 1.00  
 Objective Function OF = 381158.50

Flow zones		Low	Medium	High	Flood
Lower limits ML, HL, FL (ac-ft/month)	=	0.	848.	5743.	21528.
Upper limits LU, MU, HU (ac-ft/month)	=	848.	5743.	40602.	
Months of low, medium, high, flood flows	=	175	174	208	208
Mean of known flows (acre-feet/month)	=	276.	2579.	18165.	79378.

Mean of Initial Computed Flows (ac-ft/m)	=	3853.2
Mean of Initial B(m) Flows (ac-ft/month)	=	429.7

Initial Parameter Calibration Results Prior to Gradient Search: Non-Flood

Objective function OF = 381158.500  
 Number of times objective function computed = 407294  
 Z1,Z5,Z9,Z13 = 117894.6 7328.7 10404.0 633.56  
 Z2,Z6,Z10,Z14 = 8916.1 5618.8 1521.0 879.07  
 Z3,Z7,Z11,Z15 = 8127.0 5525.5 16.0 5626.55  
 Z4,Z8,Z12,Z16 = 12751.5 7552.3 42436.0 7981.24  
 B(m) = 437.0 1280.3 908.3 942.5 1305.7 28.0  
           0.0 0.0 0.0 0.0 45.8 208.3  
 X(1,j) = 0.910000 1.000000 0.070000 0.950000 1.000000  
 U(1) = 0.240 U(2) = 1.060 DX = 1.0000 BX = 1.00000

Results After Gradient Search But Before Final DX Calibration: DX = 1.0000  
 Number of times drought index activated = 356  
 Number of months with known and computed flows below 0.0 ac-ft = 44 167  
 Number of objective function evaluations = 409303  
 Objective Function OF = 371956.312

Z1,Z5,Z9,Z13 =	116484.5	7427.7	10201.0	516.58
Z2,Z6,Z10,Z14 =	9116.5	5689.5	1156.0	834.16
Z3,Z7,Z11,Z15 =	8048.9	5461.9	4.0	5545.17
Z4,Z8,Z12,Z16 =	0.0	0.0	0.0	0.00

#### Final Parameter Calibration Results: Non-Flood

Period-of-analysis is 1940 through 1997

Means of known and computed flows = 26881.5 4007.1 acre-feet/month

Limits based on known flows:

Means of known and computed low flows =	275.6	373.9	acre-feet/month
Means of known and computed medium flows =	2579.4	1969.4	acre-feet/month
Means of known and computed high flows =	18165.2	4714.4	acre-feet/month
Means of known and computed flood flows =	79378.3	8698.5	acre-feet/month
Number of months of low, medium, high, and flood flows =	175	174	208 208

Limits based on computed flows:

Means of known and computed low flows =	1390.1	48.3	acre-feet/month
Means of known and computed medium flows =	14447.0	2848.4	acre-feet/month
Means of known and computed high flows =	69065.7	9610.9	acre-feet/month
Means of known and computed flood flows =	218849.5	25825.3	acre-feet/month
Number of months of low, medium, high, and flood flows =	224	260	212 2

Number of times drought index activated = 9

Number of months with known and computed flows below 0.0 ac-ft = 44 167

Number of search cycles and objective function evaluations = 16 and 415306

Objective Function OF = 360561.219

Z1,Z5,Z9,Z13 =	121362.5	7381.2	2401.0	1272.64
Z2,Z6,Z10,Z14 =	8415.6	5031.4	7225.0	555.54
Z3,Z7,Z11,Z15 =	7989.7	5358.3	9.0	5484.93
Z4,Z8,Z12,Z16 =	12681.8	7493.4	42436.0	7928.42

Non-Flood Multiplier Factor U(1) = 0.250000  
Exponent U(2) = 1.060000  
Base Flow Factor BX = 1.000000  
Drought Index Factor DX = 5.593777

Final Parameters in Input Record Format NAEA66 Non-Flood

QD	1	611											
QA	0	925.00											
BM		0.00	1360.33	988.33	1022.50	1385.67	82.06	0.00	0.00	0.00	0.00	52.81	0.00
XP	611	0.91081256	1.00000000	0.06994399	0.94999999	1.00000000							

\*\*\* FE record was read for control point NAEA66.  
\*\*\* FP record was read for control point NAEA66.  
\*\*\* Starting FE record parameter optimization Flood

Initial Enumeration X(1,j) = 0.80 1.00 0.10 1.00 1.00  
U(1) = 0.40 U(2) = 1.20 BX = 1.00  
Objective Function OF = 14326.54  
Refined Enumeration X(1,j) = 0.86 1.00 0.10 0.95 1.00  
U(1) = 0.35 U(2) = 1.24 BX = 1.00  
Objective Function OF = 12841.46

Flow zones		Low	Medium	High	Flood
Lower limits ML, HL, FL (ac-ft/month) =	0.	848.	5743.	21528.	
Upper limits LU, MU, HU (ac-ft/month) =	848.	5743.	40602.		
Months of low, medium, high, flood flows =	175	174	208	208	
Mean of known flows (acre-feet/month) =	276.	2579.	18165.	79378.	

Mean of Initial Computed Flows (ac-ft/m) = 27537.4  
Mean of Initial B(m) Flows (ac-ft/month) = 429.7

#### Initial Parameter Calibration Results Prior to Gradient Search: Flood

Objective function OF = 12841.465  
Number of times objective function computed = 235928  
Z1,Z5,Z9,Z13 = 1602937.2 7449.6 2601.0 44890.09  
Z2,Z6,Z10,Z14 = 408218.8 6278.1 121.0 45775.53  
Z3,Z7,Z11,Z15 = 25461.3 4568.3 2809.0 686.94  
Z4,Z8,Z12,Z16 = 3762.9 2737.3 9.0 77.65  
B(m) = 262.2 768.2 545.0 565.5 783.4 16.8  
0.0 0.0 0.0 0.0 27.5 125.0  
X(1,j) = 0.860000 1.000000 0.100000 0.950000 1.000000  
U(1) = 0.350 U(2) = 1.240 DX = 5.5938 BX = 1.00000

#### Final Parameter Calibration Results: Flood

Period-of-analysis is 1940 through 1997  
Means of known and computed flows = 26881.5 27614.7 acre-feet/month

#### Limits based on known flows:

Means of known and computed low flows = 275.6 865.7 acre-feet/month  
Means of known and computed medium flows = 2579.4 8157.8 acre-feet/month  
Means of known and computed high flows = 18165.2 23060.1 acre-feet/month  
Means of known and computed flood flows = 79378.3 72536.6 acre-feet/month  
Number of months of low, medium, high, and flood flows = 175 174 208 208

#### Limits based on computed flows:

Means of known and computed low flows = 1443.9 53.3 acre-feet/month  
Means of known and computed medium flows = 10605.3 1914.7 acre-feet/month  
Means of known and computed high flows = 25310.0 20808.2 acre-feet/month  
Means of known and computed flood flows = 69690.0 83232.6 acre-feet/month  
Number of months of low, medium, high, and flood flows = 226 163 156 210

Number of times drought index activated = 9  
Number of months with known and computed flows below 0.0 ac-ft = 44 169

Number of search cycles and objective function evaluations = 62 and 240508  
Objective Function OF = 12720.639  
Z1,Z5,Z9,Z13 = 1623055.8 7451.1 2601.0 45837.64  
Z2,Z6,Z10,Z14 = 411939.8 6287.1 144.0 46609.97  
Z3,Z7,Z11,Z15 = 25517.1 4557.7 2809.0 717.15  
Z4,Z8,Z12,Z16 = 3760.9 2725.6 4.0 74.29

Flood Multiplier Factor U(1) = 0.350000  
Exponent U(2) = 1.240000  
Base Flow Factor BX = 1.000000  
Drought Index Factor DX = 5.593777

#### Final Parameters in Input Record Format NAEA66 Flood

QD 1 611  
QA 0 925.00  
B4 572.20 833.20 840.00 875.50 1093.40 326.80 310.00 50.00 310.00 0.00 337.50 435.00  
X4 611 0.85999995 1.00000000 0.10009999 0.95000011 1.00000000

\*\*\* Finished hydrologic period-of-analysis extension routine.

Date: 07/13/2012  
Beginning Time: 03:10:47  
Ending Time: 04:56:50

\*\*\*\*\* Normal Completion of Program WRAP-HYD \*\*\*\*\*

The level 1 calibration process controlled by the *HYD* input HIN file of Table 6.12 can be tracked through the *HYD* message HMS file presented as Table 6.13. Intermediate as well as final results are recorded in the HMS file. Other options not activated in the HIN file of Table 6.12 allow much more detailed intermediate results than the summary information included in Table 6.13. The *HYD* output HOT file of Table 6.14 contains the set of parameter values resulting from the level 1 calibration of the flow model (Eqs. 1, 2, 3, 4, 5). The HOT output file of Table 6.14 contains *BM*, *XP*, *B4*, and *X4* records and *UB* record input data comprising a calibrated set of parameter values which are used to create the HIN file reproduced as Table 6.15.

Table 6.14  
Program *HYD* Output HOT File for Level 1 Parameter Calibration

```

*** WRAP-HYD Output File CalOUT.HOT
***
LRCA58      Non-Flood
Multiplier factor U(1) and Exponent U(2) = 0.86457 0.82473
Base Flow Factor BX = 0.960000
Drought Index Factor DX = 1.571017
BM          2947.67 5440.00 5440.00 5440.00 5440.00 5440.00 2714.83 1173.50 1473.50
1456.17 2001.17 1957.83
XP 710 0.28870958 0.85737497 0.32454535 0.95933706 0.94999999
XP 610 0.71711218 0.94999999 0.40000001 0.95000011 1.00000000
XP 609 0.81450635 1.00000000 0.00002257 0.55124998 1.00000000
XP 711 0.94999999 1.00000000 0.41894999 1.00000000 0.97999999
XP 709 0.85737509 0.94999999 0.38000000 0.94999999 0.97999999
XP 509 0.94762510 1.00000000 0.38000000 0.98000002 1.00000000
XP 508 1.00000000 1.00000000 0.40000001 1.00000000 0.97999999
LRCA58      Flood
Multiplier factor U(1) and Exponent U(2) = 0.35311 1.10049
Base Flow Factor BX = 1.000000
Drought Index Factor DX = 1.571017
B4          2407.67 3207.94 3825.31 1953.13 8200.30 6744.71 1989.83 901.83 496.75
994.00 646.33 731.61
X4 710 0.38423160 1.00000000 0.32385236 0.90250009 1.00000000
X4 610 0.78945827 0.98973340 0.40000001 0.98000002 1.00000000
X4 609 0.95141560 1.00000000 0.00016040 0.55786967 0.97854763
X4 711 1.00000000 0.97941959 0.40080041 0.98000002 1.00000000
X4 709 0.79017901 0.94999999 0.36761713 0.95570862 1.00000000
X4 509 1.00000000 1.00000000 0.42000002 0.88710600 1.00000000
X4 508 0.86166883 0.94999999 0.40000001 1.00000012 1.00000000
NAEA66      Non-Flood
Multiplier factor U(1) and Exponent U(2) = 0.25000 1.06000
Base Flow Factor BX = 1.000000
Drought Index Factor DX = 5.593777
BM          0.00 1360.33 988.33 1022.50 1385.67 82.06 0.00 0.00 0.00
0.00 52.81 0.00
XP 611 0.91081256 1.00000000 0.06994399 0.94999999 1.00000000
NAEA66      Flood
Multiplier factor U(1) and Exponent U(2) = 0.35000 1.24000
Base Flow Factor BX = 1.000000
Drought Index Factor DX = 5.593777
B4          572.20 833.20 840.00 875.50 1093.40 326.80 310.00 50.00 310.00
0.00 337.50 435.00
X4 611 0.85999995 1.00000000 0.10009999 0.95000011 1.00000000

```

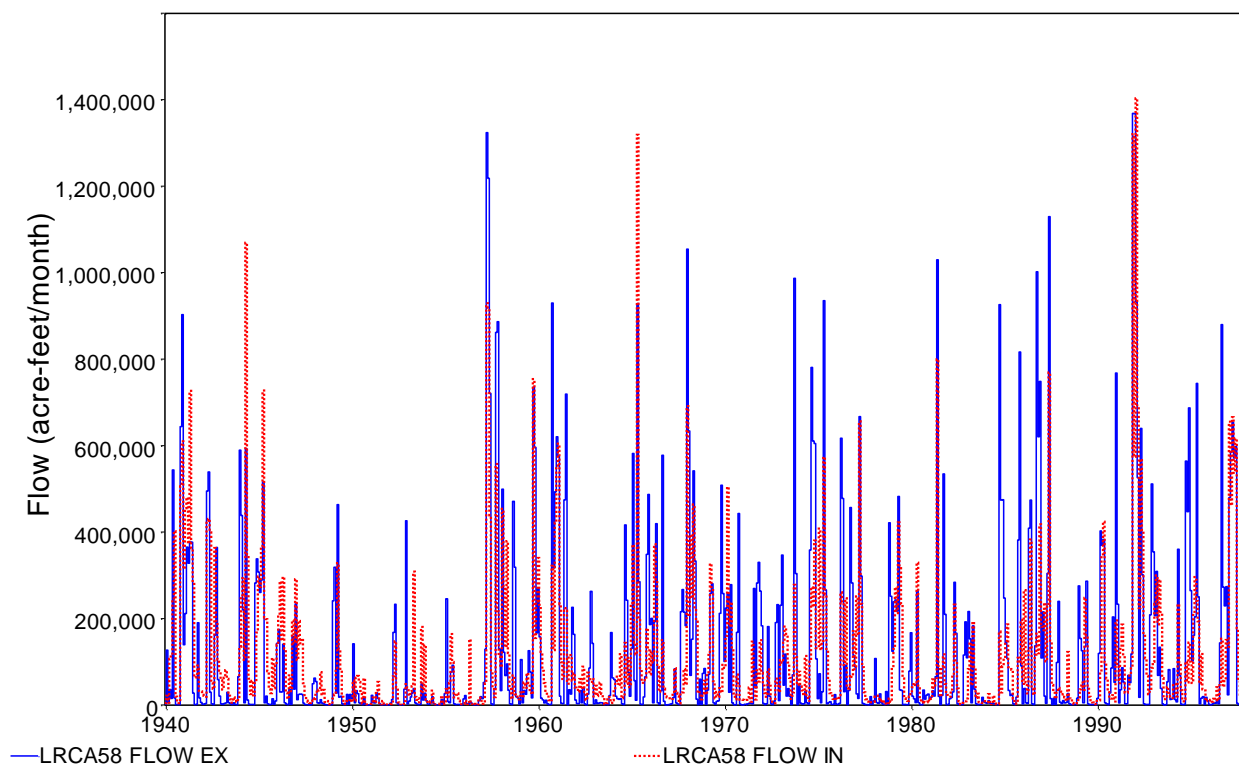


Figure 6.7 Known and Computed Flows at LCRA58 based on Level 1 Calibration

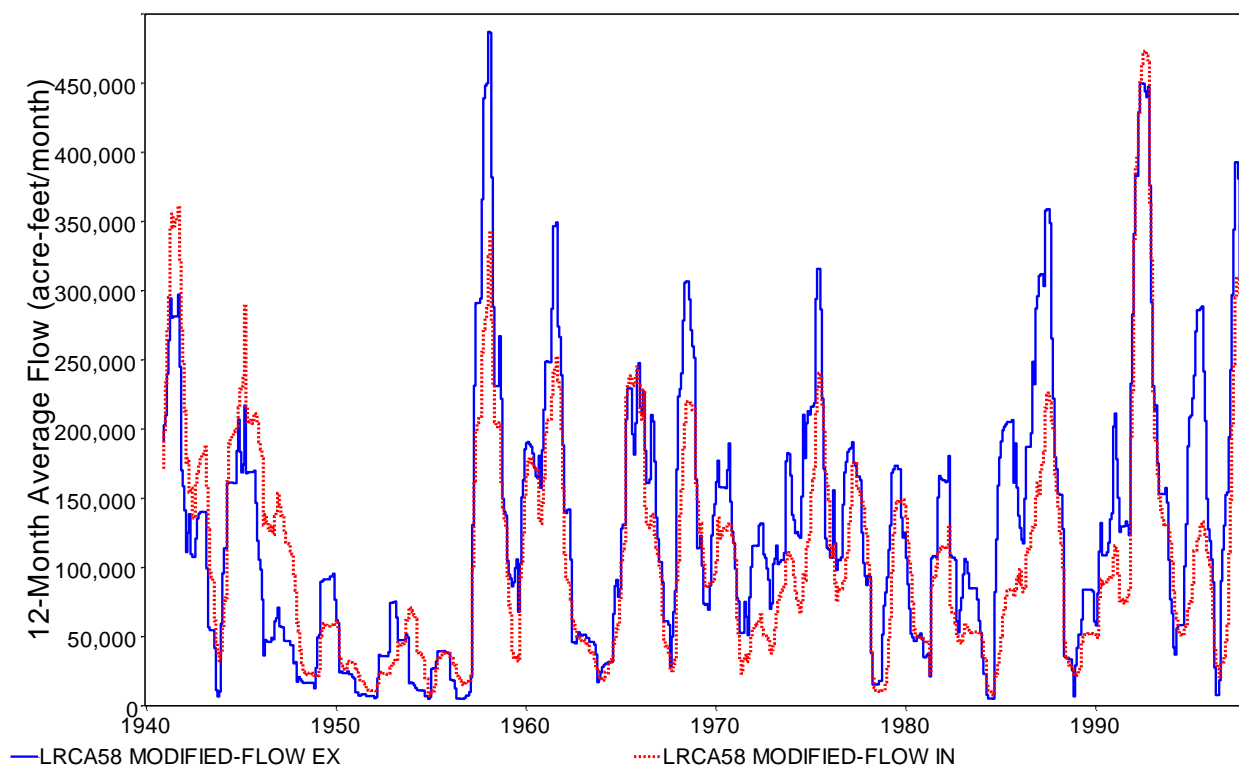


Figure 6.8 12-Month Forward Moving Average of Flows at LCRA58 with Level 1 Calibration

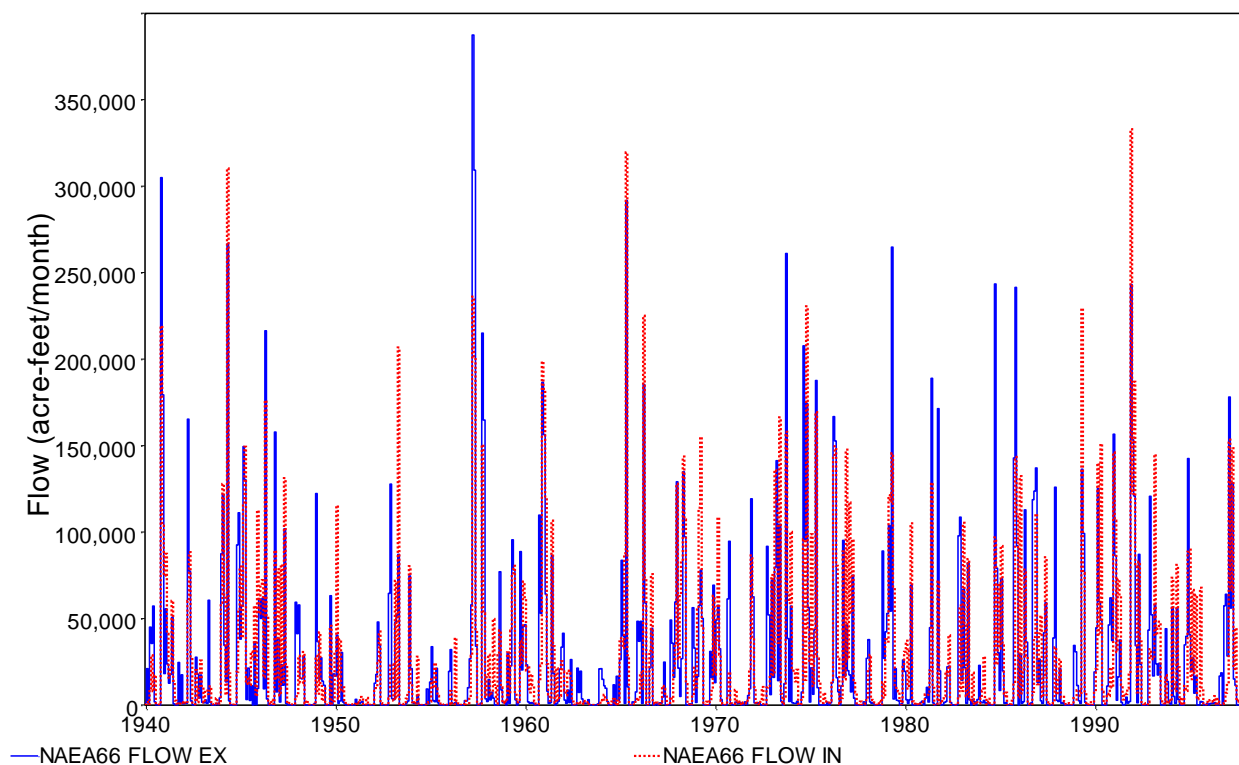


Figure 6.9 Known and Computed Flows at NAEA66 based on Level 1 Calibration

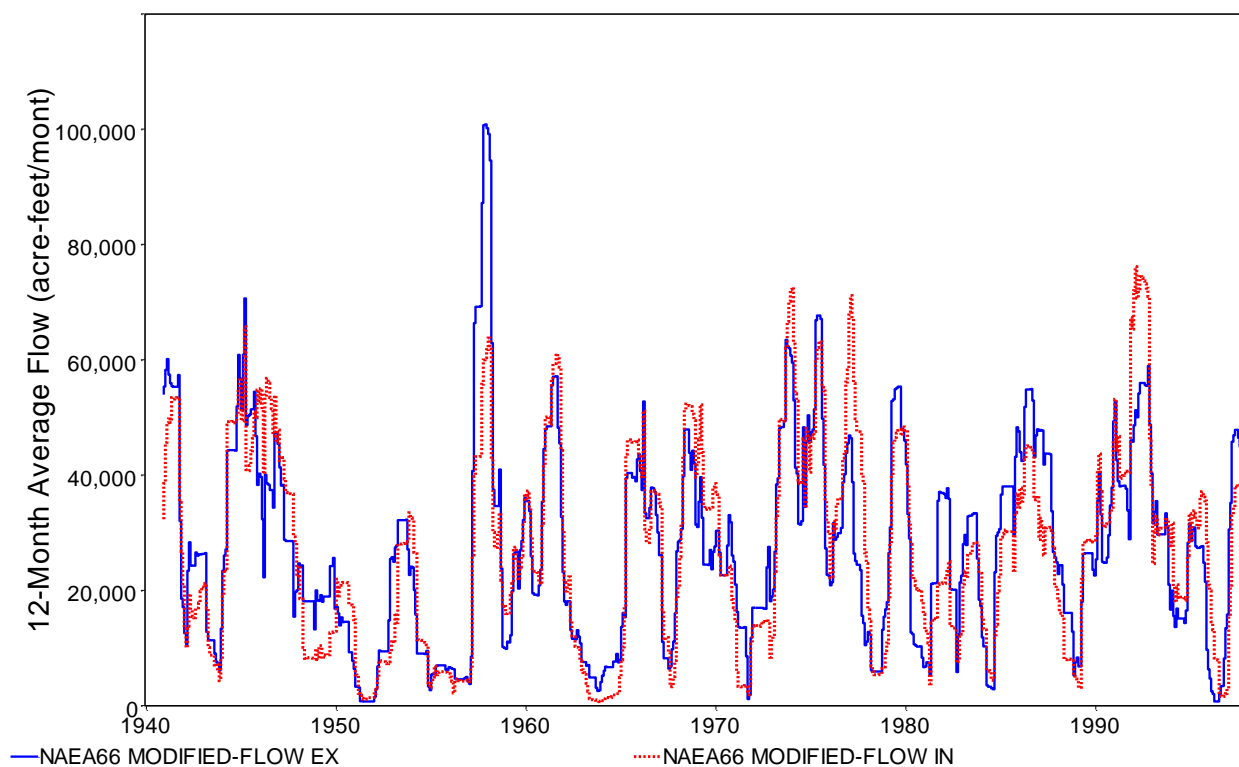


Figure 6.10 12-Month Forward Moving Average of Flows at NAEA66 with Level 1 Calibration

A solid blue line is used in all of the plots for flows computed with the *HYD* flow model and a dotted red line is used for the known flows from the WAM dataset. In the legend, IN refers to the known flows (read by *HYD* from *IN* records) and EX refers to the extended flows.

Figures 6.7-6.10 compare the 1940-1997 flows computed with the level 1 calibrated flow model (Eqs. 1, 2, 3, 4, 5) with the original known flows. The 12-month moving averages in Figures 6.9 and 6.11 are the average of flows over a 12-month period that includes the current month and following 11 months. Flow frequency metrics are provided in Tables 6.10 and 6.11.

All of the plots in the example were prepared with HEC-DSSVue from DSS files created with *HYD*. Tables 6.8, 6.9, 6.18, and 6.19 were prepared with *TABLES* with a 2NAT record. The frequency metrics in Tables 6.10 and 6.11 were created with *TABLES* with a 2FRE record using *SIM* and *TABLES* input datasets shown in Tables 6.5 and 6.6.

The final product of the level 1 calibration process is the *HYD* input HIN file of Table 6.15 less the *FR* and *FX* records and the two parameters in the *UB* record fields 2 and 3 which were added during the level 2 calibration. The *BM*, *XP*, *B4*, and *X4* records in the HOT output file of Table 6.14 are cut and pasted into the HIN input file of Table 6.15. The entries for the parameters U(1), U(2), and BX on the *UB* record in the HIN file are also derived from level 1 calibration results provided in the *HYD* output HOT file.

### Level 2 Calibration

Separate flow models (Eqs. 1, 2, 3, 4, 5) are developed for two flow ranges, labeled non-flood (low and normal flows) and flood (higher flows), in the level 1 calibration process as outlined in the preceding section. The first model is applicable for flows below the HU limit of 104,549 and 40,602 acre-feet/month, respectively for LRCA58 and NAEA66, respectively. The second model is for flows above 65,294 and 21,528 acre-feet/month. The flow models reproduce known flows most accurately in the central portion of the flow range for which they are applicable and are less accurate toward the edges of the flow range. Predictions tend to be high for lower flows and low for higher flows. The tendencies for low and high predictions are further complicated by the overlaps between flow ranges. The level 2 calibration process using *FR* and *FX* records consists of developing adjustments to correct for these tendencies inherent in the flow models. The level 2 calibration factors are based on replicating the frequency statistics of the known flows presented in Tables 6.10 and 6.11.

The HIN file of Table 6.15 containing the parameter values from the level 1 calibration provides the basis for the level 2 calibration. *HYD* is executed to develop 1940-1997 sequences of flows computed with the extension model which are compared with the known flows. Model adjustments added with *FR*, *FX*, and *UB* records are developed based on this comparison.

Flow frequency relationships for the known flows and flows computed with the level 1 calibrated model were developed with *TABLES* with the TIN file of Table 6.6 and are reproduced in the first three columns of Tables 6.10 and 6.11. The *FR* and *FX* records in the HIN file of Table 6.15 were developed from these frequency relationships as shown in Tables 16 and 17. The *FX* records created by *HYD* contain the ratios of the means of the known and computed flows in each of the flow ranges defined by the limits provided as input on the *FR* records.

**Table 6.15**  
**Final *HYD* Input HIN File for Extending Flows for 1998-2012**

```

** WRAP-HYD Input File Ext.HIN for Flow Extension for
** Cameron Gage Control Point on Little River and Easterly Gage Control Point on Navasota River
**
JC 1940 58 1 2 2
CPLRCA58
CPNAEA66
**      1      2      3      4      5      6      7      8      9      10
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234
**      !      !      !      !      !      !      !      !      !      !      !      !      !      !
** Flow Extension for Control Point LRCA58
FELRCA58 1998 2012 1940 1997 2 0 1.571017
FN      Ext1998-2012
QD 4 7 710 610 609 711 709 509 508
QA      1896. 1470. 2129. 77. 324. 1063. 115.
FZ      11904.0 28988.2 104549. 65294.4
FR 2 2706.4 5440.0 11904.0 19040.8 28988.2 44799.0 65294.4 104549. 165070. 290433. 426869.
FR 2 900.18 1126.60 1690.02 3309.56 6237.68 18829.9 34369.7 109140. 233080. 459524. 617683.
FX      2.17672 3.76835 6.27838 6.28063 5.00212 2.72622 2.10532 1.29145 0.77472 0.71145 0.67270 0.78651
UB 900. 630. 0.86457 0.82473 0.960 0.35311 1.10049 1.00
BM      2947.67 5440.00 5440.00 5440.00 5440.00 5440.00 2714.83 1173.50 1473.50 1456.17 2001.17 1957.83
XP 710 0.28870958 0.85737497 0.32454535 0.95933706 0.94999999
XP 610 0.71711218 0.94999999 0.40000001 0.95000011 1.00000000
XP 609 0.81450635 1.00000000 0.00002257 0.55124998 1.00000000
XP 711 0.94999999 1.00000000 0.41894999 1.00000000 0.97999990
XP 709 0.85737509 0.94999999 0.38000000 0.94999999 0.97999990
XP 509 0.94762510 1.00000000 0.38000000 0.98000002 1.00000000
XP 508 1.00000000 1.00000000 0.40000001 1.00000000 0.97999990
B4      2407.67 3207.94 3825.31 1953.13 8200.30 6744.71 1989.83 901.83 496.75 994.00 646.33 731.61
X4 710 0.38423160 1.00000000 0.32385236 0.90250009 1.00000000
X4 610 0.78945827 0.98973340 0.40000001 0.98000002 1.00000000
X4 609 0.95141560 1.00000000 0.00016040 0.55786967 0.97854763
X4 711 1.00000000 0.97941959 0.40080041 0.98000002 1.00000000
X4 709 0.79017901 0.94999999 0.36761713 0.95570862 1.00000000
X4 509 1.00000000 1.00000000 0.42000002 0.88710600 1.00000000
X4 508 0.86166883 0.94999999 0.40000001 1.00000012 1.00000000
** Flow Extension for Control Point NAEA66
FENAEA66 1998 2012 1940 1997 2 0 5.593777
QD 1 611
QA      925.
FZ      848.0 5743.0 40601.6 21528.2
FR 2 594.8 848.0 1342.6 2576.8 5743.0 11059.6 21528.2 40601.6 87562.4 131425.
FR      0.0 52.8 234.92 1313.02 2473.30 11341.7 22551.0 45369.3 87922.3 136475.
FX      1.00000 0.66753 3.0 2.07545 2.31076 1.43512 0.94324 0.90205 1.02340 0.96439 0.90411
UB      0.25000 1.06000 1.00 0.350 1.240 1.00
BM      0.00 1360.33 988.33 1022.50 1385.67 82.06 0.00 0.00 0.00 0.00 52.81 0.00
XP 611 0.91081256 1.00000000 0.06994399 0.94999999 1.00000000
B4      572.20 833.20 840.00 875.50 1093.40 326.80 310.00 50.00 310.00 0.00 337.50 435.00
X4 611 0.85999995 1.00000000 0.10009999 0.95000011 1.00000000
ED

```

The level 2 calibration consists of multiple executions of *HYD* to develop the sets of up to eleven QR(r) on two *FR* records, up to twelve FX(r) on a *FX* record, FX(13) on the *FX* record, and ZF(1) and ZF(2) on the *UB* record. The following parameters were added to the HIN file of Table 5.15 during the level 2 calibration for control points LRCA58 and NAEA66, respectively.

```

FR 2 2706.4 5440.0 11904.0 19040.8 28988.2 44799.0 65294.4 104549. 165070. 290433. 426869.
FR 2 900.18 1126.60 1690.02 3309.56 6237.68 18829.9 34369.7 109140. 233080. 459524. 617683.
FX 2.17672 3.76835 6.27838 6.28063 5.00212 2.72622 2.10532 1.29145 0.77472 0.71145 0.67270 0.78651
UB 900. 630.

```

FR	2	594.8	848.0	1342.6	2576.8	5743.0	11059.6	21528.2	40601.6	87562.4	131425.
FR		0.0	52.8	234.92	1313.02	2473.30	11341.7	22551.0	45369.3	87922.3	136475.
FX		1.00000	0.66753	3.0	2.07545	2.31076	1.43512	0.94324	0.90205	1.02340	0.96439 0.90411

The two flow range *FR* records for LRCA58 contain the eleven known and computed flows in Table 6.16 with specified exceedance frequencies. The *FX* record contains the ratios of the means of the know and computed flows in each of the twelve flow ranges defined by the sets of eleven limits provided on the *FR* records. The two *FR* records were developed manually from the flow frequency relationships of Tables 6.16 and 6.17. The *FX*(r) on the *FX* record were computed by *HYD* for the given quantities provided as input on the *FR* records. The *FR* and *FX* records for NAEA66 were developed in the same way except the number of ranges is reduced because zero computed flow is associated with exceedance frequencies of 75 percent and greater.

Table 6.16  
Level 2 Calibration Factors Defined by *FR* and *FX* Records for LRCA58

Exceedance Frequency	Known Flow (ac-ft/m)	Computed Flow (ac-ft/m)	Mean of Known Flows (ac-ft/m)	Mean of Computed Flows (ac-ft/m)	<i>FX</i> 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

The *HYD*-computed *FX* record ratios of flow means for control point LRCA58 reproduced in the last column of Table 6.16 were incorporated without change into the HIN file.

The *HYD*-computed *FX* record ratios for control point NAEA66 reproduced in the last column of Table 6.17 were incorporated into the HIN file with one ratio being changed based on judgment. The ratio of 12.80785 for the third flow range ( $Q_{75\%} \leq Q_C < Q_{70\%}$ ) was reduced to 3.0.

Table 6.17  
Level 2 Calibration Factors Defined by *FR* and *FX* Records for NAEA66

Exceedance Frequency	Known Flow (ac-ft/m)	Computed Flow (ac-ft/m)	Mean of Known Flows (ac-ft/m)	Mean of Computed Flows (ac-ft/m)	<i>FX</i> Record Factors
80%	594.8	0.0	162.8	0.0	1.00000
75%	848.0	52.8	723.2	0.0	1.00000
70%	1,342.6	234.9	1,029.1	80.3	12.80785
60%	2,576.8	1,313.0	1,891.8	911.5	2.07545
50%	5,743.0	2,473.3	3,992.4	1727.7	2.31076
40%	11,060	11,342	8,139.6	5671.7	1.43512
30%	21,528	22,551	16,254	17232	0.94324
20%	40,602	45,369	30,095	33,363	0.90205
10%	87,562	89,922	63,436	61,986	1.02340
5%	131,425	136,475	107,539	111,510	0.96439
			183,228	202,660	0.90411

The purpose of the parameters ZF(1) and ZF(2) in *UB* record fields 1 and 2 is to refine the model to better replicate zero and near-zero flows. Values of 900 acre-feet/month and 630 acre-feet/month are assigned for ZF(1) and ZF(2) on the *UB* record for control point LRCA58. Computed flows of 900 acre-feet or less are adjusted by subtracting 630 acre-feet, while setting resulting negative numbers to zero. The HMS file includes counts of the number of months of zero flows and the five smallest known and computed flows, which are used to develop values for ZF(1) and ZF(2). The known flows include two months of zero flow and the five smallest non-zero flows copied below from the HMS file. The corresponding computed flows without and with the ZF(1)=900 and ZF(2)=630 adjustments are also shown below.

known	0.0	0.0	42.0	194.0	207.0	357.0	383.0	acre-feet
computed	289.1	290.8	699.4	793.1	834.9	873.3	984.8	acre-feet
final computed	0.0	0.0	69.4	163.1	204.9	243.3	984.8	acre-feet

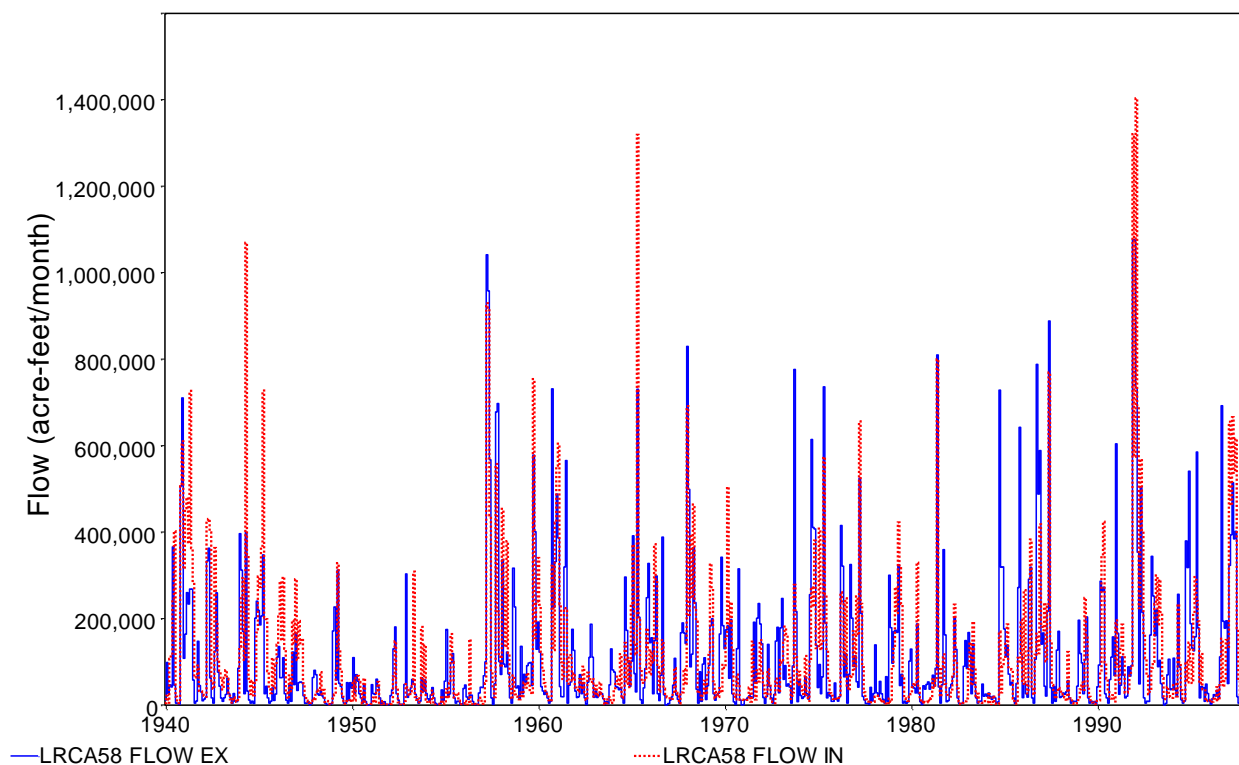


Figure 6.11 Known and Computed 1940-1997 Monthly Flows at LRCA58

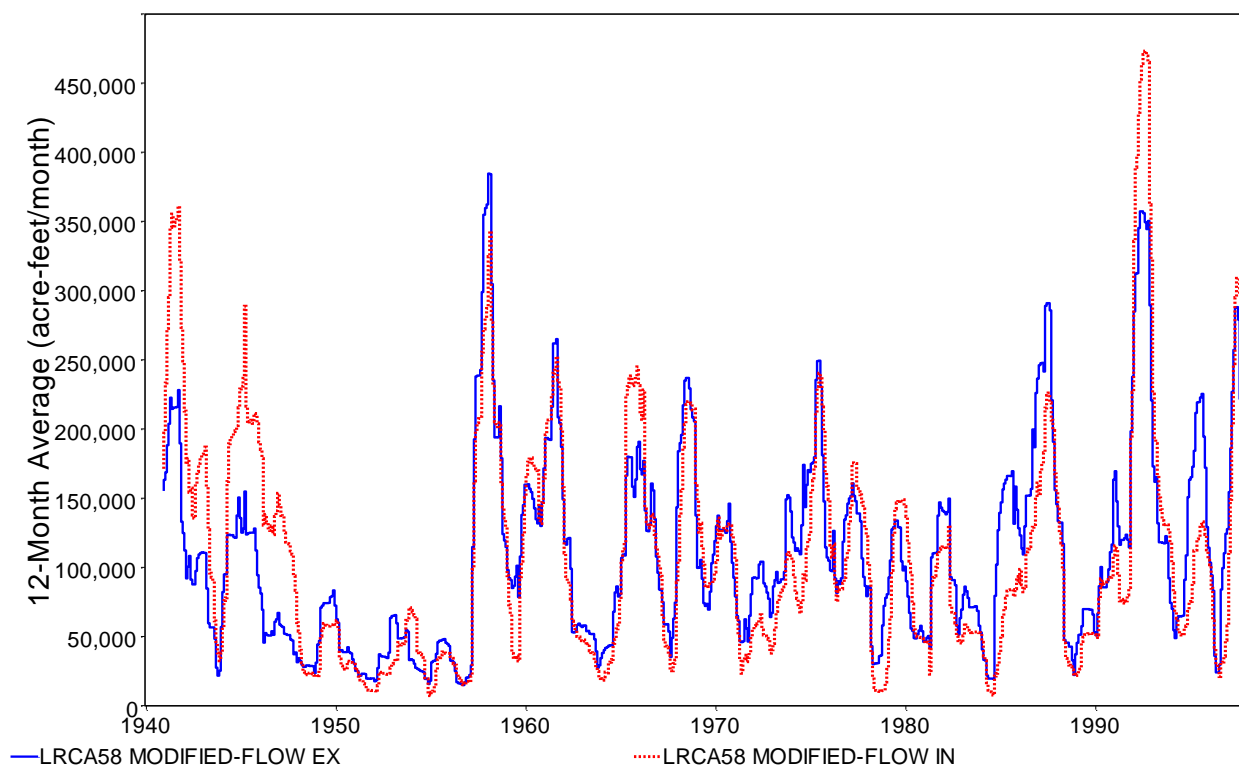


Figure 6.12 12-Month Forward Moving Average of Flows at LRCA58

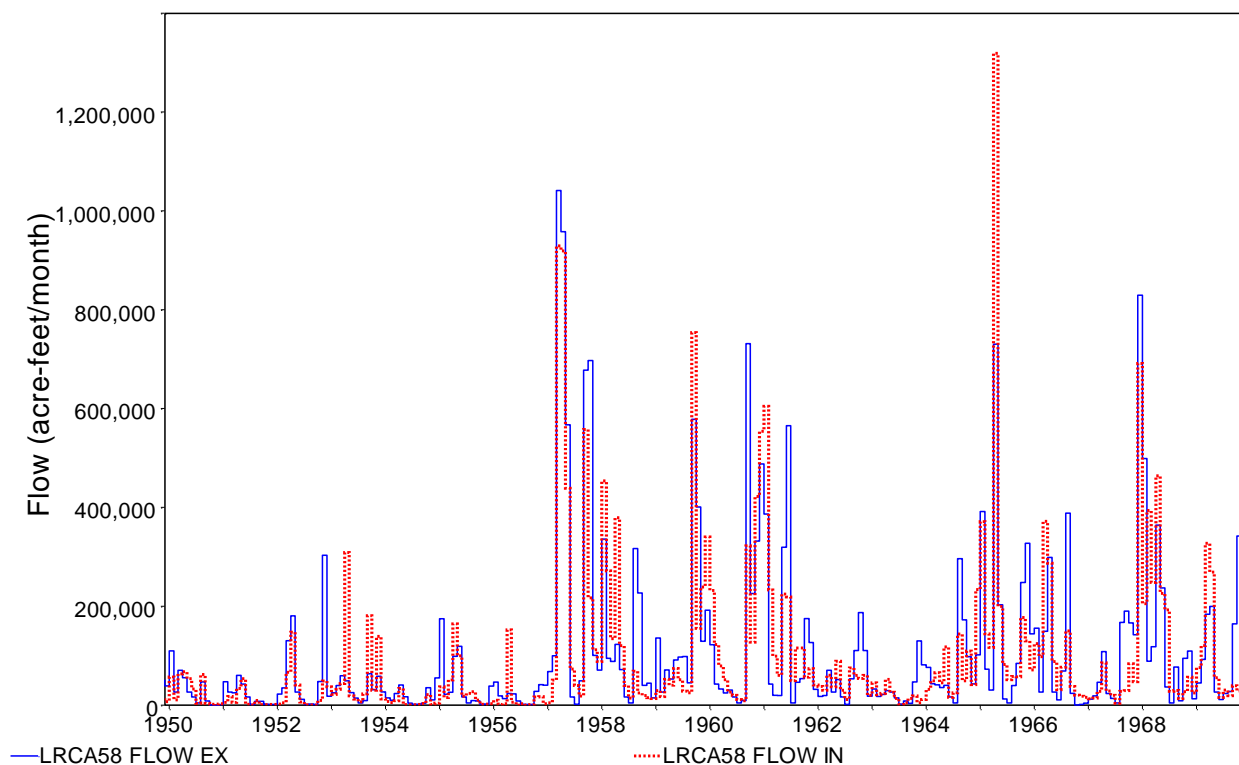


Figure 6.13 Known and Computed 1950-1969 Monthly Flows at LRCA58

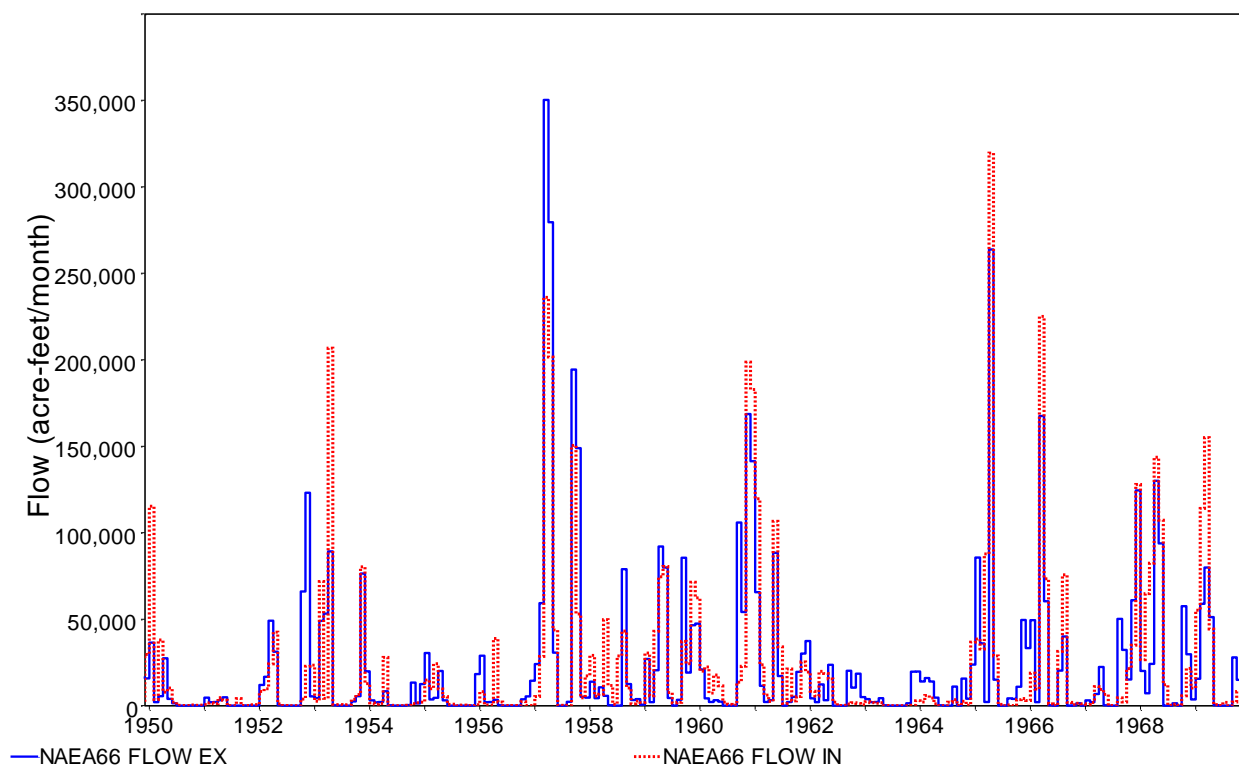


Figure 6.14 Known and Computed 1950-1969 Monthly Flows at NAEA66

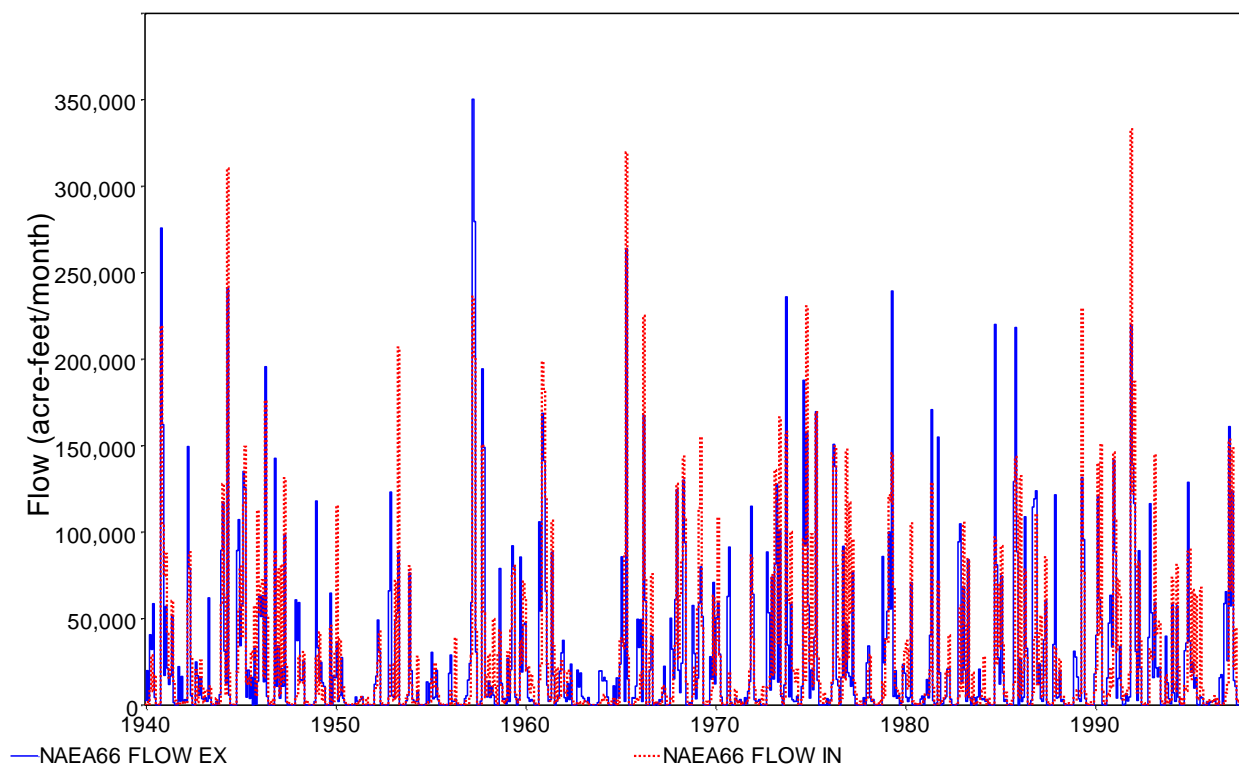


Figure 6.15 Known and Computed 1940-1997 Monthly Flows at NAEA66

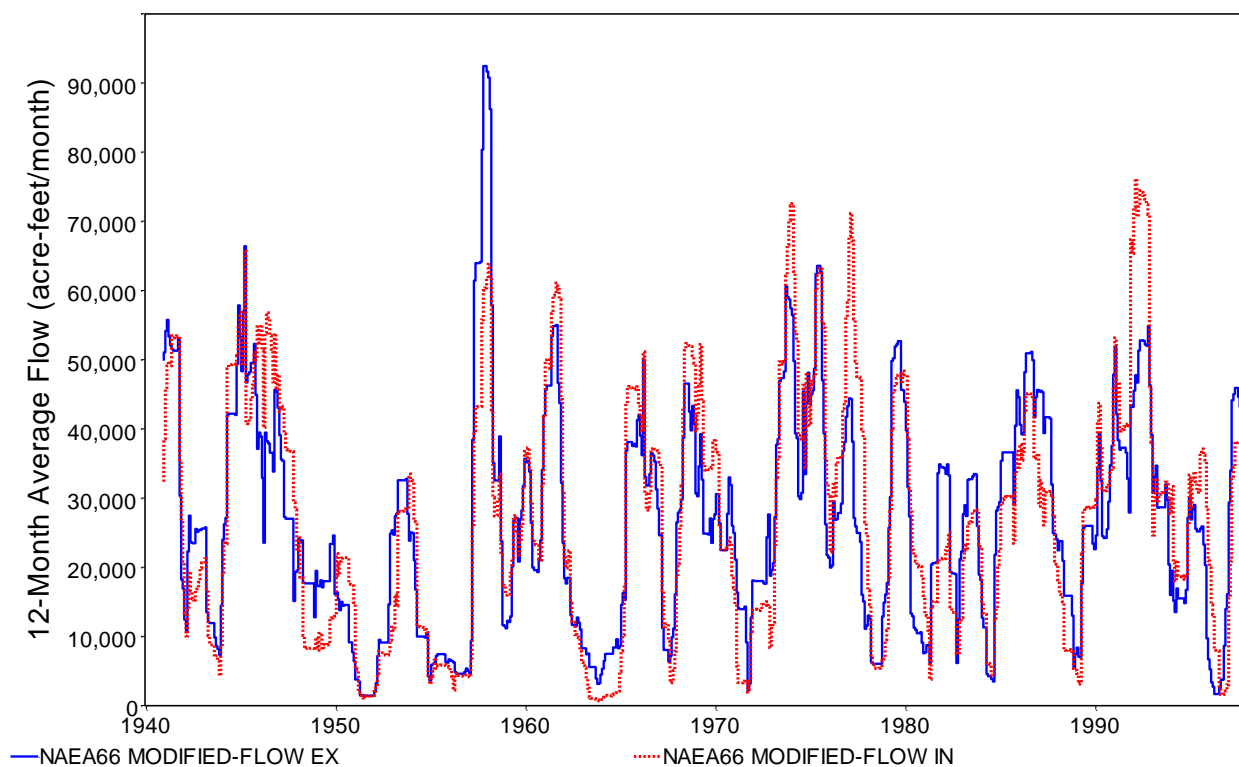


Figure 6.16 12-Month Forward Moving Average of Flows at NAEA66

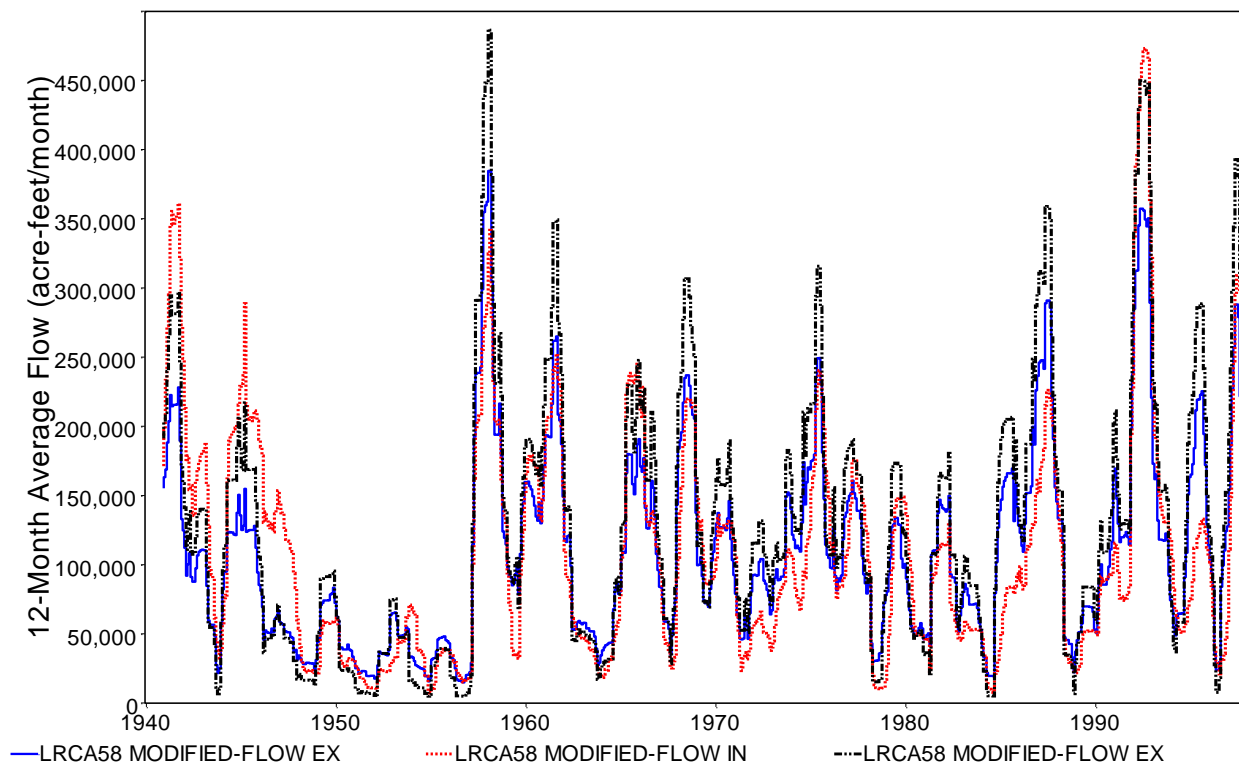


Figure 6.17 12-Month Forward Moving Average of Flows at LRCA58

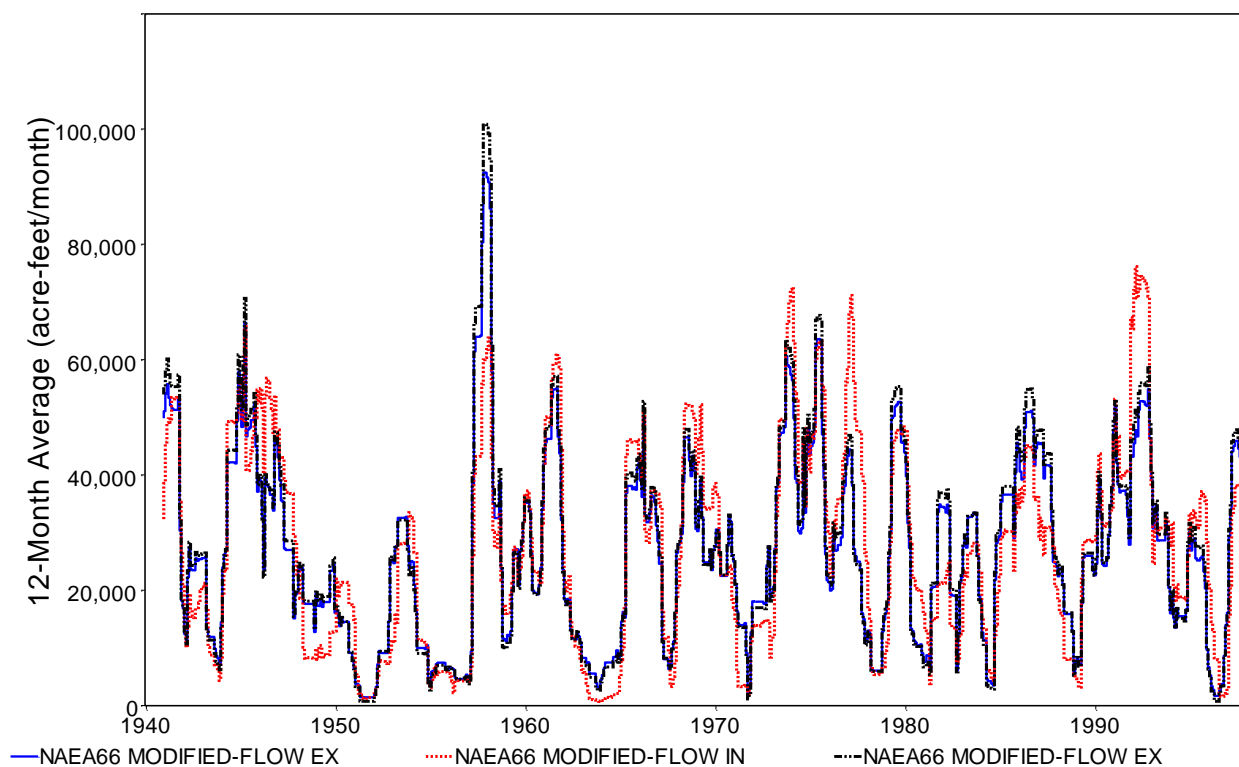


Figure 6.18 12-Month Forward Moving Average of Flows at NAEA66

The 1940-1997 monthly naturalized flows computed with the final flow extension model after completion of the level 2 calibration process are plotted in Figures 6.11 and 6.15 along with the known flows for comparison. The annual means plotted in Figures 6.12 and 6.16 include the current month and following 11 months. The 1960-1969 monthly computed and known flows in Figures 6.13 and 6.14 include the 1950's most hydrologic severe drought-of-record. Computed flows are plotted as a solid blue line. Known flows are plotted as a dotted red line.

Figures 6.17 and 6.18 are plots of 12-month forward moving averages comparing three sequences of 1940-1997 monthly naturalized flows. Known flows are plotted as a dotted red line. Flows computed with the model at the completion of the level 1 calibration are plotted as a dashed black line. Flows computed with the final model at the completion of the level 2 calibration are plotted as a solid black line.

The level 2 calibration adjustments have relatively minimal impacts on the annual flows for NAEA66 but have greater impacts for LRC58. The blue line is a little closer than the black line to the dotted line in Figures 6.17 and 6.18 in some years, but in general the annual computed flows from the level 1 and level 2 calibrated models are close. The level 2 adjustments replicate 1940-1997 means and result in increasing flows in some months and decreasing flows in other months. There is an averaging out of the monthly flow changes over a year. However, the level 2 calibration significantly improves the flow frequency metrics tabulated in Tables 6.10 and 6.11.

As indicated in Table 6.10, the mean of 696 monthly known flows at control point LRCA58 is 109,858 acre-feet/month. The computed flows for the 696 months of 1940-1997 average 129,565 and 109,710 acre-feet/month at the completion of level 1 and level 2 calibration, respectively. Thus, with only level 1 calibration, the 1940-1996 mean computed flow is 117.94 percent of the 1940-1997 mean known naturalized flow. The level 2 calibration FX(r) factor adjustments are designed to reproduce the period-of-analysis mean, which it does for the 109,858 (109,710) acre-feet/month mean at control point LRCA58.

The 1940-1997 mean of the known flows for control point NAEA66 shown in Table 6.11 is 26,882 acre-feet/month. The computed flows average 27,615 and 26,770 acre-feet/month at the completion of level 1 and level 2 calibration, respectively. Thus, with only level 1 calibration, the 1940-1996 mean computed flow is 102.73 percent of the 1940-1997 mean known naturalized flow. The final model after level results in 696 computed flows that average 99.58 percent rather than 100.00 percent of the mean of the known flows due to the FX(r) factors of 1.0 and 3.0 that were set to deal with zero and almost-zero flows.

In addition to replicating long-term means, the level 2 calibration factors are designed such that 1940-1997 computed flows replicate the standard deviations and flow frequency relationships of the 1940-1997 known flows tabulated in Tables 6.10 and 6.11. The standard deviations of 165,869 and 46,988 acre-feet/month for the computed flows closely approximate the known flow standard deviations of 170,466 and 46,900 acre-feet/month. If the flow range limits are referenced to known flows rather than computed flows, the flows for each specified exceedance frequency can be reproduced exactly. However, flows are not known for the extension period. With ranges defined based on computed flows, the flows adjustments result in some months switching between ranges. Thus, the flow versus frequency metrics are replicated reasonably closely but not exactly.

The greatest deviations between computed and known flows for control point LRCA58 occur during the mid-1940's. Streamflow, precipitation, and evaporation measurement methods and the number of gaging stations may have changed after the 1940's. Evaporation measurement methods are known to have been modified in the early 1950's and precipitation and streamflow data collection may have changed as well. Though not documented, the flow extension computations were repeated for comparison using a 1948-1997, rather than 1940-1997, period-of-analysis. The calibration with the shortened period-of-analysis results in a different set of parameter values and a slightly closer replication of 1948-1997 monthly flows. However, the change in 1998-2012 extended flows is minimal. Unlike LRCA58, control point NAEA66 does not exhibit a notably greater deviation between known and computed flows during the 1940's. The *HYD* software allows the period-of-analysis to easily be shortened. Use of 1940's data is an issue that could be investigated further.

The greatest deviations between computed and known flows for control point NAEA66 occur during extreme flood events. Differences between computed and known flows during a small number of extreme flood events are also large at control point LRCA58. The temporal distribution of an extreme flood over two months versus one month may sometimes be an issue. Flows during one or a few extreme flood events may be determined independently of the flow extension model based on gaged flow data.

The multiplier factors  $FX(r)$  defined by flow range  $FR$  and flow multiplier factor  $FX$  records and the zero and near-zero flow adjustment parameters  $ZF(1)$  and  $ZF(2)$  on a  $UB$  record were applied in the level 2 calibration in the example. Other optional level 2 calibration features available in *HYD* are briefly noted as follows.

Though not used in the example, the multiplier factor  $FX(13)$  may be entered in  $FX$  record field 2.  $FX(13)$  is similar to the up to 12  $FX(r)$  applied in  $FX$  record fields 3 through 14 for individual flow ranges. However, all computed flows are multiplied by  $FX(13)$ . It is not limited to a specified range.  $FX(13)$  can be applied either in combination with or in lieu of the  $FX(r)$  for individual flow ranges. For example, as previously noted, the 1940-1997 mean of the level 1 calibration computed flows at control point NAEA66 is 99.583 percent of the mean of the 1940-1997 known flows. A  $FX(13)$  of 1.0044 (computed as  $1.0/0.99583=1.0042$ ) could be added to the  $FX$  record so that the 1940-1997 mean of the computed flows would exactly match the 26,882 acre-feet/month mean of the known flows. This option was not adopted in the example simply because the 99.583% is very close to 100.00% and on the conservatively low side of 100.00 percent.

*HYD* also allows any number of  $FX$  records with any combinations of  $FX(13)$  and  $FX(r)$  to be used at the same control point. Level 2 could conceivably, though probably not likely, include multiple iterations that accumulate sets of  $FX$  record factors used in combination.

*HYD* also includes a linear and/or nonlinear regression and correlation analysis feature that was not used in the example. Regression coefficients entered on a  $RC$  record can be used instead of multiplier factors on a  $FX$  record. However, the  $FX$  record option is recommended over the  $RC$  record option. The  $FX(r)$  factors in Tables 6.10 and 6.11 exhibit patterns that are difficult to accurately model with a single regression equation. The  $FX(r)$  factors can be viewed as coefficients for 12 linear regression models applied separately for each of 12 flow ranges.

## Final Model for Extending Naturalized Flows

The final flow extension model consists of the program *HYD*, the HIN file of Table 6.15, and the files *Precipitation.PPP* and *Evaporation.EEE*. The format in which the naturalized flows are recorded in output files is specified by JC(8) in *JC* record column 48. JC(8) options 2 and 6 send the flows to a FLO file or DSS file, respectively. The 1998-2012 extended flows in the FLO file created with *HYD* are tabulated in Tables 6.18 and 6.19 which were developed with *SIM* and *TABLES* using the input files of Tables 6.3 and 6.4. Plots of the 1940-2012 and 1998-2012 naturalized flows created with *HEC-DSSVue* are presented as Figures 6.15 through 6.18.

Table 6.18  
Extended 1998-2012 Naturalized Flows at the Cameron Gage on the Little River (LRCA58)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	96291.	269319.	151852.	26123.	15275.	16235.	16369.	4245.	104931.	713873.	401829.	202888.	2019229.
1999	33763.	15920.	63707.	28374.	74181.	34097.	16369.	4245.	57.	1882.	7859.	27523.	307977.
2000	107242.	47628.	32727.	31114.	46185.	48662.	16369.	0.	1777.	53835.	840601.	379495.	1605634.
2001	183212.	91531.	373714.	42996.	69332.	26123.	14750.	58122.	52586.	44465.	290678.	365580.	1613088.
2002	40723.	41946.	38664.	26123.	19969.	51048.	236861.	4245.	8881.	407184.	280248.	261298.	1417190.
2003	139639.	255403.	49047.	19829.	15617.	73327.	26968.	4245.	62680.	121687.	53369.	3797.	825609.
2004	105719.	288259.	102216.	266431.	214244.	771426.	197132.	55970.	52437.	324686.	1243912.	332224.	3954656.
2005	87814.	129902.	45338.	21906.	65138.	26123.	16369.	67194.	8881.	1173.	1776.	1026.	472640.
2006	7912.	31077.	50238.	47818.	41050.	26123.	16369.	1906.	8358.	73962.	12066.	54539.	371417.
2007	344147.	26123.	560662.	282527.	755815.	1066250.	1156342.	28467.	43038.	8777.	33080.	10895.	4316123.
2008	9332.	12828.	60191.	63961.	43857.	18970.	9808.	4245.	8881.	7597.	9351.	1070.	250092.
2009	1824.	13689.	63756.	93254.	48760.	20883.	16369.	4245.	413659.	1060390.	349490.	50025.	2136344.
2010	179372.	362168.	102517.	44584.	21753.	23815.	50574.	4245.	295863.	8777.	1216.	3869.	1098752.
2011	62012.	34015.	12925.	7615.	17753.	16828.	1464.	0.	1026.	31217.	112024.	254594.	551473.
2012	290548.	391262.	549378.	26123.	53453.	26123.	42303.	4245.	64299.	8777.	949.	186.	1457645.
MEAN	112637.	134071.	150462.	68585.	100159.	149736.	122294.	16375.	75157.	191219.	242563.	129934.	1493191.

Table 6.19  
Extended 1998-2012 Naturalized Flows at the Easterly Gage on the Navasota River (NAEA66)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1998	87636.	109188.	4332.	2122.	2598.	30.	0.	0.	71377.	222780.	164961.	68914.	733937.
1999	97528.	5310.	2051.	4351.	9885.	3616.	0.	0.	0.	0.	158.	3861.	126761.
2000	4849.	4846.	16628.	4763.	32588.	88318.	0.	0.	0.	12621.	192626.	113962.	471203.
2001	86393.	48055.	106302.	3588.	4653.	19230.	0.	0.	10300.	9913.	62883.	158433.	509748.
2002	14913.	3904.	13824.	2122.	3202.	246.	1219.	0.	0.	129180.	72849.	154539.	395998.
2003	5581.	94895.	6266.	2122.	3202.	9855.	0.	0.	4013.	27482.	16601.	1948.	171964.
2004	4307.	63977.	4724.	21510.	28449.	282026.	6519.	1627.	0.	51403.	264734.	17259.	746535.
2005	12482.	23588.	5602.	2122.	4480.	246.	0.	3638.	0.	0.	158.	0.	52316.
2006	0.	19173.	11904.	5165.	3215.	246.	0.	0.	0.	23297.	3954.	13062.	80016.
2007	131005.	5361.	128579.	20501.	228312.	173929.	130986.	0.	0.	0.	158.	1712.	820542.
2008	0.	3143.	26150.	5607.	7444.	246.	0.	12757.	3711.	0.	158.	0.	59217.
2009	0.	3143.	11827.	84016.	4590.	246.	0.	0.	40455.	226626.	63640.	3358.	437901.
2010	13975.	48304.	7101.	2690.	3202.	526.	1844.	0.	0.	0.	158.	0.	77801.
2011	12594.	9644.	2051.	2122.	3202.	246.	0.	0.	0.	0.	158.	33436.	63454.
2012	64292.	59220.	150581.	4027.	3202.	246.	0.	0.	2564.	738.	34.	0.	284905.
MEAN	35704.	33450.	33195.	11122.	22815.	38617.	9371.	1201.	8828.	46936.	56216.	38032.	335487.

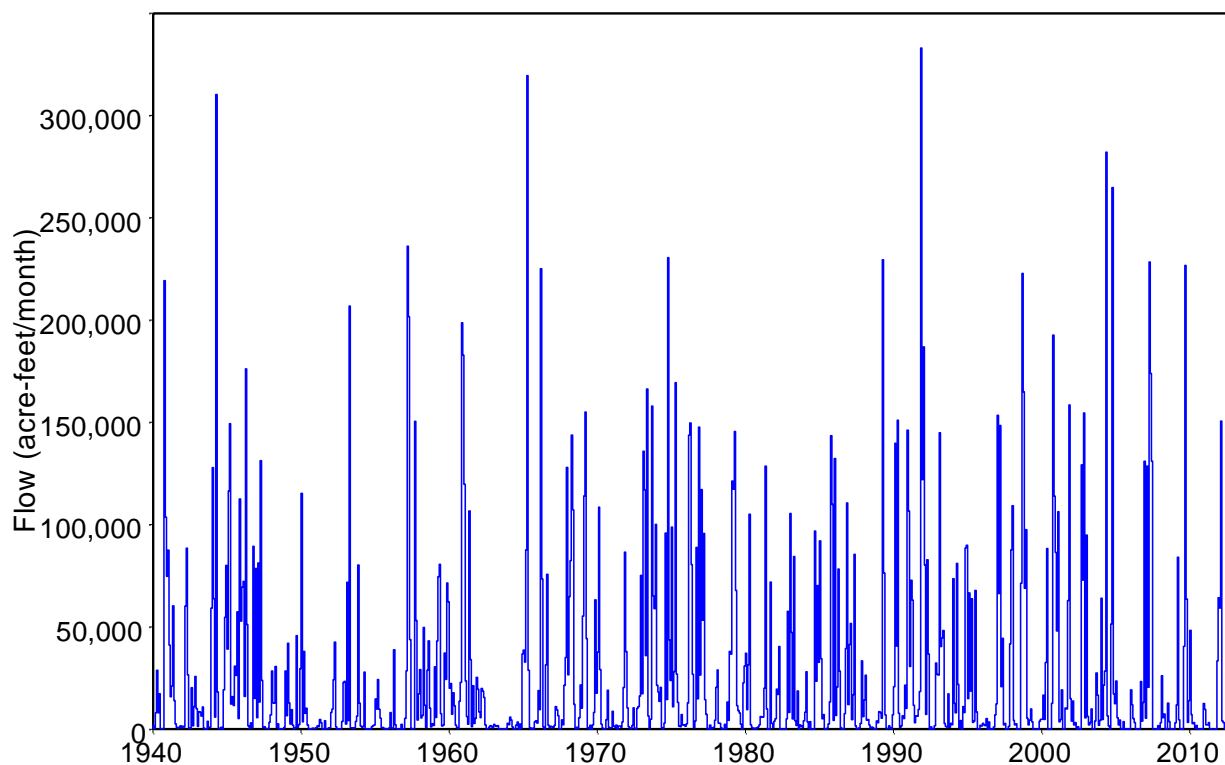


Figure 6.19 Original 1940-1997 and Extended 1998-2012 Naturalized Flows at LRCA58

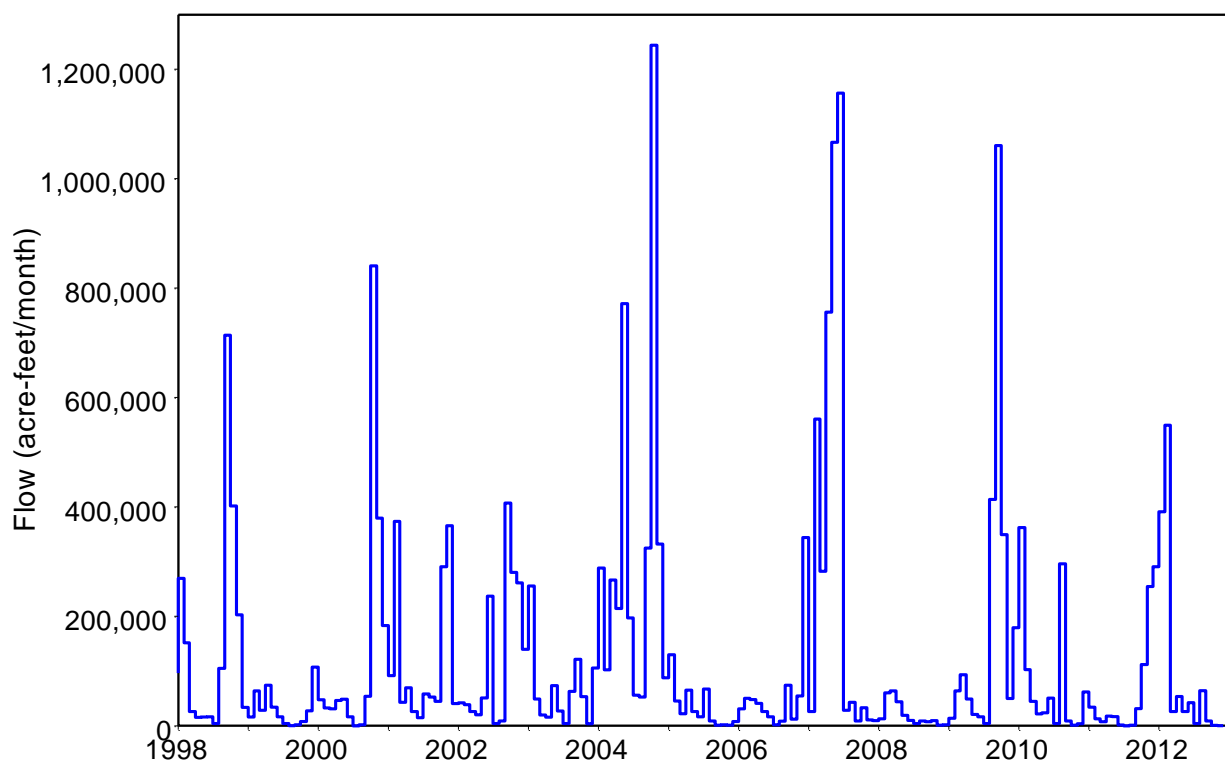


Figure 6.20 Extended 1998-2012 Naturalized Flows at LRCA58

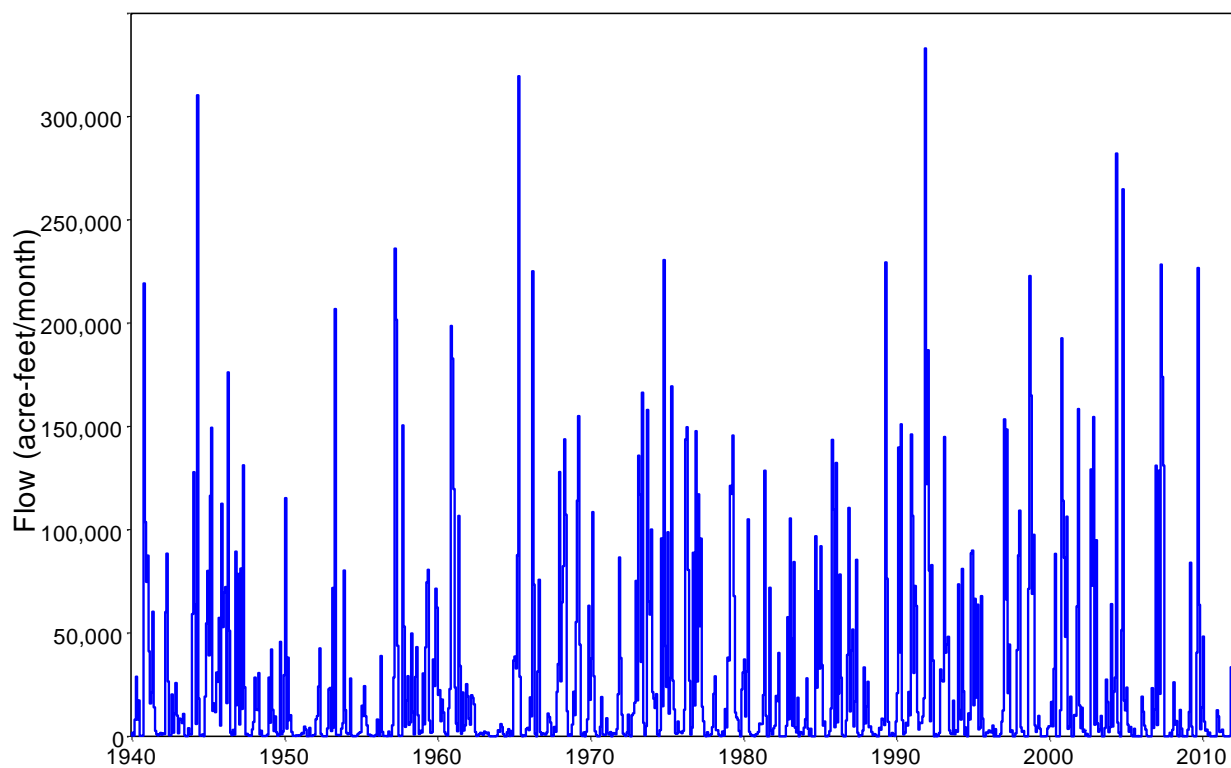


Figure 6.21 Original 1940-1997 and Extended 1998-2012 Naturalized Flows at NAEA66

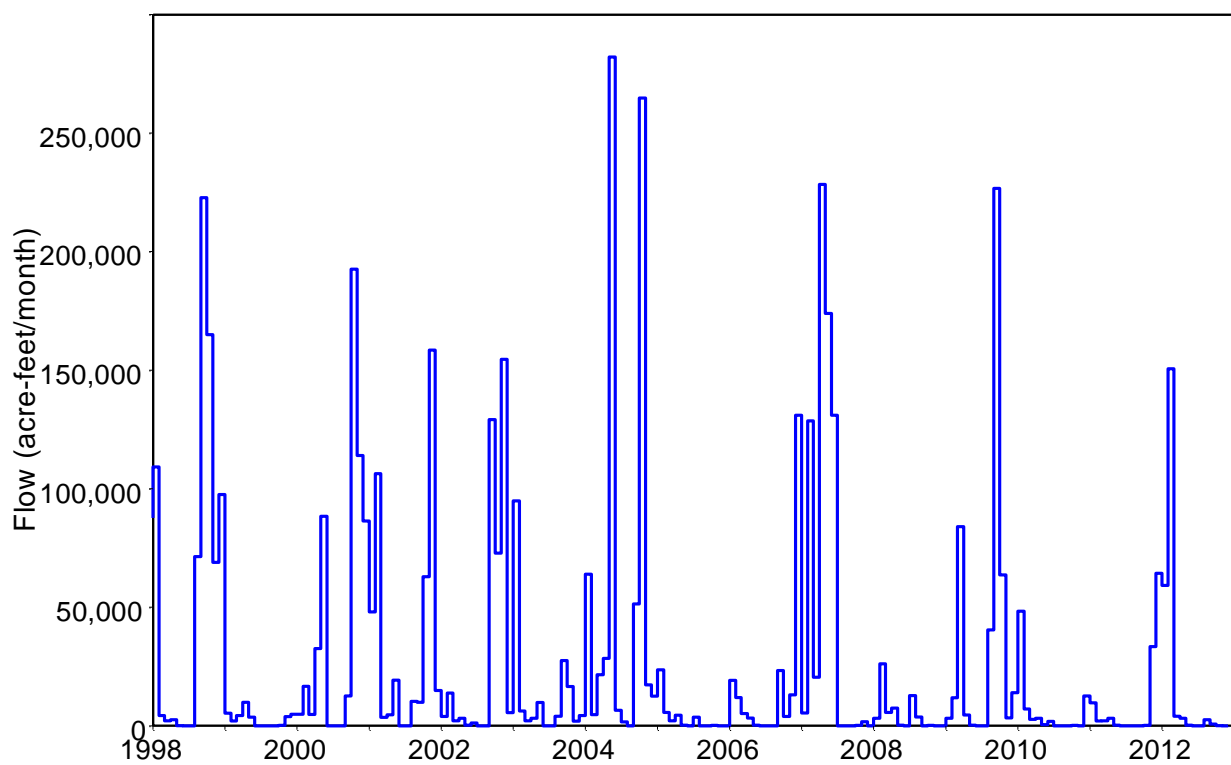


Figure 6.22 Extended 1998-2012 Naturalized Flows at NAEA66

### **Recommended Flow Extension Strategy Illustrated by the Example**

The WRAP program *HYD* provides capabilities for constructing a model that computes naturalized monthly stream flows as a function of monthly precipitation and evaporation rates. The model calibration process consists of finding a set of parameter values that replicate the characteristics of the known period-of-analysis naturalized flows as closely as possible. The calibrated model is then applied to estimate flows for the period-of-extension. Input records required to calibrate and apply the model are described in the last section of this document.

The TWDB updates the precipitation and evaporation datasets each year by adding data for the preceding calendar year. Upon completion of a calibrated flow model, the model can be reapplied each year to carry the naturalized flows forward along with the observed precipitation and evaporation rates. The only change required in the *HYD* input HIN file to update the model is a simple revision of the ending year on the *FE* record.

Flexible capabilities for developing and experimenting with a flow extension model are provided by an assortment of *HYD* options. Various strategies can be adopted for combining the various options to develop a calibrated flow extension model. A recommended standard strategy is illustrated by the preceding example and further explained as follows. This general strategy can be modified with other alternative *HYD* options as necessary to assure optimal model results in particular applications.

#### **Model Accuracy and Robustness**

The calibration process is based on developing a model that reproduces the known naturalized flows as closely as possible. However, the flows computed for each individual month are necessarily approximate. The WRAP/WAM modeling system is designed for developing frequency and reliability metrics rather than precisely synthesizing exact quantities in each individual month. Likewise, the flow model and its calibration are designed to capture the relevant statistical characteristics of the naturalized flows while producing reasonably accurate flow sequences. The goal is to replicate means, standard deviations, and flow frequency relationships along with reasonable patterns of monthly flow sequences.

Different *HYD* options may result in flow models with different sets of parameter values that produce very similar extended flow sequences that are equally valid. There is probably not a single set of optimal parameter values that can be clearly differentiated as being better than all others. The flow extension methodology is very robust in that different sets of model options and sets of parameter values will yield similar results.

In the example, the optimization-based level 1 automated parameter calibration procedure computed values for 39 decision variables (parameters) for the non-flood flow model, which includes U(1), U(2), BX, DX, and 35 X(i,j), and 49 parameters for the flood flow model, which includes U(1), U(2), 12 B(m), and 35 X(i,j) for control point LRCA58. For control point NAEA66, U(1), U(2), 12 B(m), and 5 X(i,j), were determined for each of the two flow models (non-flood and flood) along with a single DX in the level 1 automated parameter calibration. The additional *FX* and *UB* record parameters are calibrated in level 2. There is an infinitely large number of possible combinations of values for these parameters. Most of the possible

combinations of parameter values will result in an unsatisfactory flow model. However, numerous combinations of parameters will result in alternative satisfactory models with about the same level of performance in synthesizing naturalized flows.

The greatest deviations between computed and known flows for control point LRCA58 occur during the mid-1940's regardless of modeling options adopted. Data collection methodologies and the number of gaging stations may have changed in later during the 1940-1997 period-of-analysis. Evaporation measurement methods were modified in the early 1950's and precipitation and streamflow data collection may have changed as well. The flow extension computations in the example were repeated for comparison using a 1948-1997 period-of-analysis. The calibration with the shortened period-of-analysis results in a different set of parameter values and a slightly closer replication of 1948-1997 monthly flows. However, the change in 1998-2012 extended flows is minimal. Control point NAEA66 does not exhibit a notably greater deviation between known and computed flows during the 1940's.

The Brazos River Basin served as an initial case study for developing and testing the flow extension methodology. NRCA58 and NAEA66 were selected essentially arbitrarily for the example from the 77 primary control points in the Brazos WAM dataset. LRCA58 and NAEA66 appear to be representative of the 77 primary control points. Control points LRCA58 and NAEA66 have watershed areas of 7,074 and 925 square miles. The watershed areas for the 77 Brazos WAM primary control points range from 77 to 36,000 square miles. Initial preliminary analyses indicate that the methodology is essentially equally valid for the full range from relatively small to extremely large watersheds.

### Watershed Quadrangle Areas

The area of each quadrangle encompassed by the watershed should be determined as accurately as practicable. However, the effects of inaccuracies are significantly mitigated by the same areas being used in both the calibration and extension computations. The synthesized flows are not expected to be extremely sensitive to relatively small inaccuracies in area estimates. Geographical information systems (GIS) will typically be applied to estimate watershed areas, though working directly with paper maps is probably also fine.

Watershed quadrangle areas were initially estimated manually for the control point LRCA58 example using paper versions of river basin and quadrangle maps, resulting in a total watershed area of 6,870 square miles. Later more refined delineations using GIS software resulted in the watershed areas shown in Table 6.4 of 7,704 square miles. However, the refined watershed delineations and area estimates have relatively minimal impact on model results.

The quadrangle identifiers and watershed areas in square miles are included in the HIN file on *QD* and *QA* records. *HYD* allows a subset of the quadrangles to be used for the following two purposes while all of the quadrangles listed on the *QD* and *QA* records are used for all of the other computations: (1) the drought index computations and (2) the FE(11) option 2 enumeration computations. The watershed above control point NAEA66 is encompassed by a single quadrangle. The control point LRCA58 watershed is located within seven quadrangles with a judgmentally selected subset consisting of the first four quadrangles listed on the *QD* record applied in the two particular computations noted above.

## Component Models for Different Flow Zones

The recommended strategy is to develop two component models, one for non-flood flows and the other for flood flows, as illustrated by the example. The flow zones are defined by Figure 6.1. The models are combined by the rules outlined in Table 6.1. The default FE(13) option 1 is adopted in *FZ* record field 2. *FE* record FE(2) options 9 and 10 are adopted for the calibration. The terms *flood* and *non-flood* flows are adopted here for the two flow zones simply to differentiate between higher flows versus low and more normal flows.

The flow extension features are organized based on alternative options for developing a single model for all flows (one model), developing separate models for non-flood (low and moderate) flows and flood (high) flows (two models), or developing separate models for low, medium, high, and flood flows (three or four models). Accurately modeling the full range from zero to extreme flood flows with a single model is difficult. During a period-of-analysis with known flows, four models will probably work best. However, with flows not known during a period-of-extension, flow zones must be defined based on computed flows. Defining zones based on computed flows causes difficulties. Thus, adoption of only two flow zones is recommended.

Non-flood and flood zones should normally be adopted and calibrated with two *FE* records as illustrated in the example. However, if model results do not appear to be satisfactory, separate models for low, medium, high, and flood flow zones (Figure 6.2, Table 6.2, FE(13) option 2, FE(2) options 1-8) should be investigated. Using four rather than two flow zones does not improve model results for the example. Two zones are definitely much better than a single zone.

In the example, the LU/ML, MU/HL, FL, and HU limits are set at flow volumes from column 2 of Table 6.10 associated with exceedance frequencies of 80%, 60%, 40%, and 30% for LRCA58 which has only two months of zero naturalized flows during the 696 month period-of-analysis. The LU/ML, MU/HL, FL, and HU limits are set at flow volumes from column 2 of Table 6.11 associated with exceedance frequencies of 75%, 50%, 30%, and 20% for NAEA66 which has 44 months of zero naturalized flows during 1940-1997 in the WAM dataset. These two sets of frequencies are considered reasonable for general applicability. However, setting the flow limits based on other exceedance frequencies can also be investigated.

## Level 1 Calibration

The automated optimization-based level 1 parameter calibration procedure is controlled by the HIN file of Table 6.12. FE(2) options 9 and 10 are selected in field 8 of the two *FE* records for the non-flood and flood models of the overall flow model. With FE(2) option 9 activated, the non-flood model is calibrated independently of the flood flow model, but the non-flood model parameters are stored in computer memory for later use during the calibration of the flood flow model as required by the combining rules of Table 6.1. With FE(2) option 10 activated, the combining rules of Table 6.1 are implemented during calibration of the flood flow model.

Alternatively, the non-flood and flood models could have both been calibrated with FE(2) option 11 selected in field 8 of each of the two *FE* records. In this case, both models are

calibrated independently of each other without needing the combining rules of Table 6.1. However, regardless of the options adopted for calibration, the combining rules of Table 6.1 must be applied in the final flow extension model. Thus, the strategy using FE(2) options 9 and 10 illustrated by the example is recommended.

The following objective functions are adopted in the example for non-flood and flood flows, respectively.

$$\begin{aligned} \text{OF} &= 1.0 \times Z1 + 1.0 \times Z2 + 1.0 \times Z3 + 3.0 \times Z5 + 3.0 \times Z6 + 3.0 \times Z7 \\ &\quad + 10.0 \times Z9 + 10.0 \times Z10 + 10.0 \times Z11 + 10.0 \times Z13 + 10.0 \times Z14 + 10.0 \times Z15 \\ \text{OF} &= 1.0 \times Z4 + 3.0 \times Z8 + 10.0 \times Z12 + 10.0 \times Z16 \end{aligned}$$

This general strategy is recommended for including Z metrics for low, medium, and high flows in the objective function for calibrating the non-flood model and Z metrics for flood flows in the objective function for calibrating the flood flow model.

All four Z metrics are included in each of the four flow zones. Including multiple Zs for each flow zone is important. A single Z representing one particular flow characteristic will not yield satisfactory results. Experimentation with various values for the weighting factors entered on the *FP* record is recommended. The objective is to select weighting factors that provide a reasonable balance between the flow characteristics represented by each of the Z metrics.

Options for developing initial estimates of parameter values prior to the univariate gradient search are activated by FE(10) and FE(11) in *FP* record fields 20 and 21. The default FE(10) option 1 consists of applying the enumeration algorithm with specified increments to develop initial estimates of parameter values that are subsequently further adjusted by the univariate gradient search. In applying the enumeration algorithm to develop initial parameter estimates, FE(11) option 1 assumes that all quadrangles have the same values for the  $X(i,j)$ . FE(11) option 2 computes separate initial estimates of  $X(i,j)$  for each quadrangle. Regardless of FE(11) option, the subsequent univariate gradient search always treats the  $X(i,j)$  as multiple decision variables that may vary between quadrangles.

The standard default FE(10) option 1 is adopted for the example. FE(11) option 2 is adopted for control point LRCA58 on the *FP* record in the HIN file of Table 6.12 as modified by specifying use of a subset of four of the seven quadrangles on the *QD* record. Since NAEA66 has only one quadrangle, FE(11) options 1 and 2 are the same and option 1 is specified.

For a control point with several quadrangles, computer runtime is dramatically greater for FE(11) option 2 than option 1. For example, using a version of the control point LRCA58 model as a test case, with FE(11) option 1, the objective function was evaluated 415,201 times and 409,115 times during the automated parameter calibration for non-flood flows and flood flows, respectively. The runtime recorded in the HMS file was 15 minutes and 13 seconds. With FE(11) option 2 activated with all seven quadrangles (no subset specified), the objective function was evaluated 12,521,313 times and 12,408,775 times during the automated parameter calibration for non-flood and flood flows, respectively, with a runtime of 6 hours and 34 minutes.

FE(11) option 2 is activated on the *FE* record for LRCA58 in the example but a subset of four of the seven quadrangles is specified on the *QD* record. The FE(11) option selection for

NAEA66 has no relevance since NAEA66 has only one quadrangle. As indicated by the HMS file in Table 6.13, the LRCA58 optimizations for non-flood and flood flows included computing values for the objective function 2,401,208 and 2,475,770 times, and the NAEA66 optimizations for non-flood and flood flows required 415,306 and 240,508 objective function evaluations. The computer runtime was one hour and 46 seconds.

The enumeration algorithm works fine with FE(11) option 1. Option 2 is not absolutely necessary. However, FE(11) option 2 serves to minimize potential problems of the gradient search algorithm converging to a local rather than global optimum solution, and thus conceptually may be more reliably accurate than option 1. However with option 2, computer execution time increases exponentially with an increase in the number of quadrangles. The strategy adopted in the example of applying FE(11) option 2 to the four quadrangles located closest to the watershed outlet and option 1 to the others represents a reasonable compromise. Option 2 is actually workable with seven quadrangles, but the computer execution time becomes excessive as the number of quadrangles increases much higher than seven.

## Level 2 Calibration

The results of the automated optimization-based level 1 parameter calibration process in a set of values for the parameters of Equations 1, 2, 3, 4, and 5. For the example, these parameter values are recorded in the *HYD* output HOT file of Table 6.14. These parameters are inserted into the *HYD* input HIN file of Table 6.15 to create a flow extension model. The flow model is applied to develop sequences of computed flows for the period-of-analysis that are compared with known flows during the level 2 calibration. The objective is to adjust the flow model to better replicate the known flows. Replication of the statistical characteristics of the known flows is a key focus of the level 2 calibration.

The recommended strategy illustrated by the example includes development of separate models for non-flood (low/normal) and flood (high) flows in the level 1 calibration process which together comprise the overall flow model. The two component flow models reproduce known flows most accurately in the central portion of the flow range for which they are applicable and are less accurate toward the outer edges of the flow range. Predictions tend to be high for lower flows and low for higher flows. The tendencies for low and high predictions are further complicated by overlaps between flow ranges. Thus, the flow extension model with level 1 calibrated parameters will tend to compute flows that deviate from known flows differently depending on different flow ranges. Level 2 calibration methods develop adjustments to correct these tendencies based on replicating the frequency statistics of the known flows.

The frequency statistics for the known WAM naturalized flows and the flows computed with the level 1 calibrated model are tabulated in the first three columns of Tables 6.10 and 6.11. The level 2 calibration develops adjustments to the flow model to minimize the deviations between the means and frequency metrics of the known and computed flows. The corresponding frequency statistics after incorporating level 2 calibration adjustments are shown in column 4 of Tables 6.10 and 6.11.

The sets of two flow range *FR* records and a *FX* record for each component flow model in the HIN file of Table 6.15 were added during the level 2 calibration. The two *FR* records

contain the monthly flow volumes from Table 6.11 that have specified exceedance frequencies. The *FX* record contains the ratios of the means of the known flows to means of computed flows in each of the flow ranges defined by the quantities provided on the *FR* records. These *FX(r)* ratios are computed automatically by *HYD* and serve as multiplier factors in the final flow extension model. The computed flows falling within each range are multiplied by the appropriate factor in the *HYD* extension computations.

All of the parameters on the *UB* record in the Table 6.15 HIN file except ZF(1) and ZF(2) were calibrated during level 1. ZF(1) and ZF(2) are added during the level 2 calibration, if needed, to improve replication of the number of zero and near-zero flows. The HMS file includes counts of zero flows and flows below a specified level and listings of the five smallest flows for both the computed and known flows that may be used to set ZF(1) and ZF(2).

### Software Tools for Comparative Analyses of Known and Computed Flows

The basic concept of the flow extension model is to first calibrate a set of parameter values which will result in the model closely reproducing the period-of-analysis monthly naturalized flows given the concurrent monthly precipitation and evaporation rates from the TWDB dataset. The calibrated model is then applied to estimate period-of-extension naturalized flows given the appropriate precipitation and evaporation sequences from the TWDB dataset.

Various software tools are available for comparative analyses of known and computed flows. *HYD* outputs flow sequences as either a FLO file or DSS file depending on the JC(8) option selected in column 48 of the *JC* record.

With JC(8) option 6 selected, the flows are stored in a DSS file to be read by HEC-DSSVue. All of the plots for the example were prepared with HEC-DSSVue. HEC-DSSVue provides flexible features for creating, editing, and comparing time series plots, computing and plotting moving averages or annual flows, performing statistical analyses, and transporting datasets to Microsoft Excel.

With JC(8) option 2 (or other alternative options) selected, the flows are stored in a FLO file designed to be read by *SIM*. The *SIM* and *TABLES* input files used in the example are shown in Tables 6.5 and 6.6. *TABLES* was used in the example to create frequency and time series tables.

The level 1 calibration computations are tracked in detail by the HMS file reproduced as Table 6.13. Various metrics and tables included in the HMS files are designed for comparative analyses of the computed and known flows. The level 2 calibration entails multiple executions of *HYD* with adjustments added between executions. A variety of information is provided in the HMS file to facilitate adjustments and analyses thereof.

*HYD* maintains a FLOW(cp,year,month) array which is fundamental to the flow calibration and extension computations. At the beginning of a *HYD* execution, the known naturalized flows are read from a FLO file and stored in the FLOW array. The FLOW array remains populated with the known flows unless overwritten by computed flows. At the end of the *HYD* execution, the flows in the FLOW array are written to a output FLO or DSS file as

specified by the JC(8) option as noted above. There is only one FLOW array. The period-of-analysis and period-of-extension are specified on the *FE* record. If 1940-1997 is entered on the *FE* record for the analysis period and 1998-2012 is entered for the extension period, at the completion of the *HYD* execution, the FLOW array will contain 1940-1997 known flows and 1998-2012 computed flows. If 1940-1997 is entered on the *FE* record for the analysis period and 1940-2012 is entered for the extension period, at the completion of the *HYD* execution, the FLOW array will contain 1940-2012 computed flows and no known flows.

A period-of-analysis is also specified in the *JD* record of the *SIM* DAT file shown in Table 6.5. This period-of-analysis must also be set appropriately when transferring *HYD* flows to *TABLES*. Only the data for the years included in the period-of-analysis specified on the *JD* record are read by *SIM* from input FLO and EVA files and written by *SIM* to its output OUT file.

## CHAPTER 7

### INPUT RECORDS FOR HYD FEATURES DESCRIBED IN CHAPTERS 3 AND 4

The *HYD* input files listed in Table 1.1 of Chapter 1 contain records specifying options and providing data to be used in the *HYD* operations. Chapter 7 describes the input records associated with the *HYD* features presented in Chapters 3 and 4. Chapter 8 describes the additional input records required for the capabilities presented in Chapters 5 and 6. The various types of records covered in this chapter and the files in which they are stored are listed in Table 7.1. The record types are labeled by a two-character identifier placed at the beginning of each record. These record identifiers provide a mechanism for organizing and referencing the input by data type.

Some of the same input record types are used in both *HYD* and *SIM*. Many *HYD* records are not used by *SIM*. Likewise, many record types associated with the main *SIM* input file are not pertinent to *HYD*. However, these records may be included in a *HYD* input HIN file and will be simply ignored by *HYD*. The following record types are used by *HYD* as well as *SIM*. The format and content of these records, described in Chapter 3 of the *Users Manual* [2], are essentially the same with either program: \*\*, *CP*, *CI*, *SV*, *SA*, *ED*, *IN*, *EV*, *FD*, *FC*, *WP*

The records listed below are unique to *HYD* and used with the *HYD* features described in Chapters 3 and 4.

*Job Control JC Record.*- The *JC* record is used to specify input and output options and various other job control parameters.

*Monthly Factor MF Record.*- The *MF* record attached to the *CP* provides a set 12 monthly multiplication or addition factors for adjusting either flows or evaporation-precipitation rates.

*OUT Input File OI Record.*- The *OI* record is used to write data read from the *SIM* output OUT file directly to the *HYD* output HOT file in a standard format as *SIM* or *HYD* input records.

*Evaporation-Precipitation EP Manipulation Record.*- The *EP* record controls the combining of reservoir evaporation, precipitation, and net evaporation-precipitation datasets.

*Annual AN Record.*- Representative flow volumes or evaporation-precipitation for each of the 12 months are determined by optional methods and assigned to extend the period-of-analysis.

*Adjustment Specifications AS Record.*- The *AS* record activates stream flow adjustment computations and controls the selection of adjustment options.

*Flow Adjustments FA Record.*- Stream flow adjustment amounts may be input on *FA* records.

*Reservoir Specifications RS Record.*- A *RS* record activates routines for computing river flow adjustments modeling the effects of a reservoir. Information needed for the computations are provided, and the selection of adjustment options is controlled.

*Storage Contents SC Record.*- Historical storage contents for a reservoir are input on *SC* records for use in developing the stream flow adjustments specified on a *RS* record.

*Equation EQ Record.*- Adjustment equation coefficients are provided on *EQ* records.

Table 7.1  
Types of *HYD* Input Records

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Basic Input File (filename root1.HIN)

Records for organizing the data management and computational tasks

**	comments or notes not read by the computer that may be inserted throughout
JC	Job Control data with basic input/output selections and other option switches
XL	multiplier factors designed primarily for use as unit conversions
OI	data from <i>SIM OUT</i> file is written to <i>HYD HOT</i> file in a standard format
EP	specification of <i>Evaporation-Precipitation</i> depth manipulations
AN	representative year of monthly flows or evaporation-precipitation rates
ED	End of Data

Records for defining control point connectivity and providing data for control points

CP	Control Point connectivity and naturalized flow, evaporation, and channel loss data
MF	Monthly Factors for arithmetic manipulation of flows and evap-precip depths
CI	Constant Inflows or outflows entering or leaving system at a control point

Records for describing storage-volume relationship for a reservoir

SV	Storage Volumes corresponding to areas on <i>SA</i> record
SA	Surface Area corresponding to volumes on <i>SV</i> record
RS	coefficients for storage-area equation may be entered on <i>Reservoir Specification</i> record

Hydrology Input Files (root1.FLO, root1.EVA, root1.HYD)

IN	<i>IN</i> flows to the system (inflow stream flow volume/month)
EV	<i>EV</i> aporation (reservoir net evaporation-precipitation depth/month)

Flow Distribution File (filename root1.DIS)

FD	<i>Flow Distribution</i> specifications for transferring flows from gaged to ungaged sites
FC	<i>Flow distribution Coefficients</i> for certain flow distribution options
WP	<i>Watershed Parameters</i> used in the flow distribution computations

Either Basic Data File or Flow File (root1.HIN or root1.FLO)

Records for Adjusting Stream Flows

AS	Adjustment Specifications for adjusting stream flows
FA	<i>Flow Adjustments</i>
RS	<i>Reservoir Specifications</i> for developing stream flow adjustments
SC	<i>Storage Contents</i> of a reservoir
EQ	coefficients for adjustment <i>EQuations</i>

---

## **Sequential Order of Input Records**

The input records are organized in the files in the sequential order outlined in Table 7.2. Other records from a *SIM* DAT file may be included in their normal sequence even though they are not used by *HYD*. The unused *SIM* records will simply be passed over when read by *HYD*.

The job control *JC* and *ED* records are the only required *HYD* input records. The *JC* record is placed at the beginning of the HIN file preceded only by optional comment records. The *ED* file is placed at the end of the HIN and DIS file. A *ED* record is also placed at the end of a FLO file if the FLO file contains *AS*, *FA*, *RS*, *SC* and *EQ* records.

The *XL*, *CP*, *CI*, *SV*, and *SA* records are applicable to both programs *HYD* and *SIM*. The format of the *CI*, *SV*, and *SA* records are identical in both *HYD* and *SIM*. The *XL* and *CP* records are almost the same in *HYD* and *SIM*, with relatively minor differences.

The *HYD CP* record has the parameter *INEV(cp)* in field 6 that is not included on the *SIM CP* record. The *MF* record attached to the *CP* record is unique to *HYD*. The optional *MF* record follows immediately after its *CP* record.

The *XL*, *CP*, *CI*, *SV*, and *SA* records are placed in the same order in both the *HYD* input HIN file and *SIM* input DAT file. The single optional *XL* record follows the single required *JC* record. The set of all *CP* records is next in the sequence, followed by the set of all *CI* records. The set of pairs of *SV/SA* records follow next. The set of *XL*, *CP/MF*, *CI*, and *SV/SA* records are followed in the *HYD* input HIN file by a group of optional *OI*, *EP*, and *AN* records.

*OI*, *EP*, and *AN* records are unique to *HYD*, not used with *SIM*. Any number of *OI*, *EP*, and *AN* records are grouped together in any order. The *OI*, *EP*, and *AN* records must be grouped together in one set, but individual records can be placed in any order within the set. All of the *OI*, *EP*, and *AN* records are read and their contents stored in memory before any computational operations controlled by them are performed.

The *EQ*, *AS*, *FA*, *RS*, and *SC* records comprise another group of *HYD* input records that are unique to *HYD*. This group of records may be placed either at the end of the HIN file or at the end of the FLO file, as specified by *JC(3)* on the *JC* record. Computations controlled by each *EQ* or *AS* record are performed prior to reading the next *AS* or *EQ* record.

An *AS* record precedes each set of *FA* records and each set of *RS/SC* records. *FA* records are grouped by control point. A *RS* record precedes each group of *SC* records. *SC* records for a control point are grouped together. *EQ* records may be before, after, or between sets of *AS/FA* records and *AS/RS/SC* records.

The hydrology *IN* and *EV* records and flow distribution *FD*, *FC*, and *WP* records are the same in either programs *HYD* or *SIM*. *IN* and *EV* records are stored in *FLO* and *EVA* files, a *HYD* file, or a *DSS* file. The organization of the *IN* and *EV* records in these input files is controlled by *JC(1)* and *JC(2)* on the *JC* record. *FD*, *FC*, and *WP* records are stored in a *DIS* file with the same sequencing when read by either *HYD* or *SIM*.

Table 7.2  
Sequential Order of Input Records

**	Comments	Comments may be inserted throughout the files.
<u>Basic Input File (filename root1.HIN)</u>		
JC	Job Control Data	JC record is preceded only by optional comment ** records.
XL	Multiplier Factors	Optional XL record follows the JC record.
CP/MF	Control Point	Set of CP/MF records follows the JC, DC, and XL records.
CI	Constant Inflows	Set of optional CI records follows set of all CP records.
SV	Storage Volumes	Set of all SV-SA record tables grouped together in any order with
SA	Surface Area	each SA record immediately following corresponding SV record.
OI	OUT input file	OI, EP, and AN records are grouped together in any order
EP	Evap-Precip	following the above records. Any number of OI, EP, and
AN	Representative Year	AN records in any order may be included in the group.
EQ, AS, FA, RS, SC		Set of stream flow adjustment records listed below.
<u>EQ, AS, FA, RS, SC records are placed at the end of either the HIN File or FLO File</u>		
AS	Adjustment Specifications	An AS record precedes each set of FA records and each
FA	Flow Adjustments	set of RS/SC records. FA records for a CP are grouped.
RS	Reservoir Specifications	A RS record precedes each group of SC records.
SC	Storage Content	SC records for a control point are grouped together.
EQ	Adjustment Equation	EQ records may be before, after, or between AS records.
ED	End of Data	ED is last record in HIN file or after adjustment records.
<u>Stream Flow File (filename root1.FLO)</u>		
IN	Inflows	IN records are grouped together by year and control point.
<u>Evaporation-Precipitation Depth File (filename root1.EVA)</u>		
EV	Evaporation	EV records are organized the same as IN records.
<u>Hydrology File (filename root1.HYD) [alternative to standard FLO and EVA files]</u>		
IN	Inflows	IN/EV records are grouped by year. Set of EV records for all control
EV	Evaporation	points for year follow set of all IN records for the preceding year.
<u>Flow Distribution File (root1.DIS)</u>		
FD	Flow Distribution	Each FC record follows the corresponding FD
FC	Flow Distribution Coefficients	record. The set of all WP records follows the set
WP	Watershed Parameters	of all FD/FC records.
ED	End of Data	

## **Content and Format of Each Type of Input Record**

The remainder of this chapter consists of a set of tables outlining the information to be entered in each field of each type of *WRAP-HYD* input record. The record identifier is entered as the first two characters of each record. Comment records are not read by the program, except for the \*\* record identifier. The other records begin with a two-character identifier, followed by a 6-character wide field and several four-character and eight-character fields. This manual describes input format in terms of fixed-width fields. However, optionally as discussed in Chapter 1, fields with integer *I* and real *F* numerical data formats may be delimited with commas.

The Fortran format specifications found in the fourth column of the following tables describing each record type are the same for all the *WRAP* programs and are illustrated as follows.

A6	alphanumeric (AN) label right justified in a field that is 6 characters wide
2x	two blank spaces (Fields with the spacing descriptor x are skipped over and not read.)
F8.0	real number in field of 8 characters with any number of digits to the right of the decimal (Either include decimal or right justify the number.)
12F8.0	twelve real numbers with each in a field with a width of 8 characters
I8	integer number right justified in field of 8 characters (Decimal is not allowed.)
3I8	three integer numbers with each right justified in field of 8 characters

Instructions regarding the content and format of each of the record types follow in essentially the sequential order in which the records are listed in Table 7.2 and sequenced in the input files.

### **\*\* Record – Comments**

field	columns	variable	format	value	description
1	1-2	CD	A2	**	Record identifier
2	3-no limit			AN	Comments which are not read by the program

Comment (\*\*) records are not read by the program, except for the \*\* identifier. They are used to insert notes in the input dataset. The two asterisks \*\* may also be used to temporarily deactivate records. Any number of comment records may be placed at the following locations.

- almost any place in the HIN file
- before the first *IN* and *EV* records for each year in the FLO and EVA files
- before each set of flow adjustment *AS* records in the HIN and FLO files
- before each set of reservoir adjustment *RS* and *SC* records in the HIN and FLO files
- before the *FD* records and between the *FD* and *WP* records in the DIS file

## ED Record – End of Data

field	columns	variable	format	value	description
1	1-2	CD	A2	ED	Record identifier

An *ED* record is required at the end of the HIN and DIS files. The *ED* record is also required at the end of a FLO file if the FLO file contains *AS*, *FA*, *RS*, *SC* and *EQ* records. The *JC* and *ED* are the only required *HYD* records. The HIN file begins with a *JC* and ends with an *ED* record.

## JC Record – Job Control

field	columns	variable	format	value	description
1	1-2	CD	A2	JC	Record identifier
2	3-8	YRST	I6	+	First year of hydrologic period-of-analysis.
3	9-12	NYRS	I4	+	Number of years in period-of-analysis.
<u>Level of Error Checks</u>					
4	16	ICHECK	I4	blank,0	Normal trace and reduced error checks.
				1	Normal error checks and input trace.
				2	<i>IN/EV</i> record check.
				3	<i>CP</i> records are copied to HMS file.
				4	<i>AS</i> and <i>EQ</i> records are copied to HMS file.
				5	<i>SV/SA</i> records are copied to HMS file.
				6	<i>IN/EV</i> records are copied to HMS file.
				7	<i>FD/FC/WP</i> records are copied to HMS file.
<u>Stream Flow Input Options</u>					
5	20	JC(1)	I4	blank,0	Stream flows are not read as input.
				1	<i>IN</i> records read from FLO file grouped by years.
				2	<i>IN</i> records from FLO file grouped by control points.
				3	<i>IN</i> records from HYD file with 6 flows per record.
				4	<i>IN</i> records from HYD file with 12 flows per record.
				5	Flows read from FLO file in columnar format.
				6	Stream flows read from DSS file.
				7	Stream flows read from OUT file.
<u>Evaporation-Precipitation Input Options</u>					
6	24	JC(2)	I4	blank,0	Evaporation-precipitation depths are not read.
				1	<i>EV</i> records from EVA file grouped by years.
				2	<i>EV</i> records from EVA file grouped by control point.
				3	<i>EV</i> records from HYD file with 6 flows per record.
				4	<i>EV</i> records from HYD file with 12 values per record.
				5	Evaporation-precip from FLO file in column format.
				6	Evaporation-precipitation depths read from DSS file.
				7	Evaporation-precipitation depths read from OUT file.

## JC Record – Job Control (Continued)

field	columns	variable	format	value	description
<u>Flow Adjustment Input Options</u>					
7	28	JC(3)	I4	blank,0 1 2 3 4	No flow adjustments from HIN and FLO files. Flow adjustment data read from HIN file. Flow adjustment data read from FLO file. Flow adjustment from HIN (1 <sup>st</sup> ) and FLO (2 <sup>nd</sup> ) files. Flow adjustment from FLO (1 <sup>st</sup> ) and HIN (2 <sup>nd</sup> ) files.
<u>SIM Output OUT File Input Flow Variable Options</u>					
8	32	JC(4)	I4	blank,0 1 2 3 4 5	Initial flows are not obtained from the OUT file. Initial flows are naturalized flows (NAT). Initial flows are regulated flows (REG). Initial flows are unappropriated flows (UNA). Initial flows are stream flow depletions (DEP). Initial flows are return flows (RFR).
<u>OUT File Input Evap-Precip Variable Options</u>					
9	36	JC(5)	I4	blank,0 1 2	Evap-precip depths are not obtained from OUT file. Evap-precip depths before runoff adjustments (EVR). Evap-precip depths after runoff adjustments (EPD).
<u>OUT Input File Format</u>					
10	40	JC(6)	I4	Blank,0,1 2	OUT file is opened as a text file. OUT file is opened as an unformatted binary file.
<u>Flow Distribution DIS File Activation</u>					
11	44	JC(7)	I4	blank,0 1	DIS file is not activated. DIS file is activated.
<u>Stream Flow Output Options</u>					
12	48	JC(8)	I4	1 2 3 4 5 6 7	FLO output file grouped by years. FLO output file grouped by control points. HOT output file grouped by years. HOT output file grouped by control points. Flows tabulated as columns in the FLO file. DSS output file. RU records created in HOT file.
<u>Evaporation-Precipitation Output Options</u>					
13	52	JC(9)	I4	1 2 3 4 5 6 7	EVA output file grouped by years. EVA output file grouped by control points. HOT output file with 6 flows per record. HOT output file with 12 flows per record. Evap-precip tabulated as columns in the EVA file. DSS output file. HOT file is opened for use with EEMSS option 3.

JC record is continued on the next page.

## JC Record – Job Control (Continued)

field	columns	variable	format	value	description
<u>Watershed Parameter Tables</u>					
14	56	JC(10)	I4	1 2 3	Incremental watershed parameter table in HOT file. Table of parameters from WP records in HOT file. Both watershed parameter tables created.
<u>Reservoir Adjustment Tables</u>					
15	60	JC(11)	I4	1	HOT file opened if not already opened.
<u>Negative Incremental Flow Options</u>					
16	64	ADJINC	I4	blank,0,1 2 3 -3	Negative incremental flows are not considered. Downstream flow adjustments are performed. Upstream flow adjustments are performed. Option 3 with secondary control points excluded.
17	68	NEGINC	I4	blank,0,1 2 3	No incremental flow adjustments written. Downstream flow adjustments written to HOT file. Upstream flow adjustments written to HOT file.
<u>Set Default for Evap-Precip Adjustment</u>					
18	72	EPADJ	I4	blank,0 -1 -2	No adjustment unless specified on CP record. Adjustments based on ungaged CP (FD field 2). Adjustments based on gaged CP (FD record field 3).
<u>DSS Message File Options</u>					
19	76	JC(12)	I4	-1 1 blank, 2 3 4 5 and 6 7 8 9	Messages are written only if HYD is aborted due to a DSS related problem. Messages that DSS file has been opened or closed. Error or warning messages if DSS problems occur. Trace of all DSS records written to DSS files. Trace of all DSS records read from DSS files. Not used. Same as option 4. Beginning level of debugging messages. Intermediate level of debugging messages. Maximum level of debugging messages.
<u>Label of First Month in DSS File</u>					
20	77-80	DSSMONTH	1x,A3	blank AN	Default is for first month to be January. First month in DSS file (JAN, FEB, MAR, ... ,DEC)
<u>Record Identifier</u>					
21	83-84	CDO	2x,A2	blank AN	CDO defaults to the record identifier IN Record identifier replacing IN on output records.

The JC record is required as the first record in the HYD input HIN file, preceded only by optional comment \*\* records.

## **Explanation of JC Record Fields**

**Fields 2 and 3:** The time period covered is defined by the starting year and length in years.

**Field 4:** The various levels of error checks and messages and trace information are described in Chapter 9 of the *Reference Manual* [1]. ICHECK option 1 should normally be selected unless needs arise for other options.

**Field 5:** JC(1) specifies the source file and format of the river flows that are read to initially fill the FLOW(cp,year,month) array. The FLOW(cp,year,month) array assigned these original flow amounts read at the beginning of an execution of *HYD* is subject to various adjustments as program execution proceeds. The dataset of flows to be read by *HYD* at the beginning of program execution may be organized in the alternative formats listed.

**Field 6:** JC(2) specifies the file source and format of the evaporation, precipitation, or net evaporation-precipitation depths that are read to initially populate the EP(cp,year,month) array.

**Field 7:** Adjustments to the FLOW(cp,year,month) array are performed as directed by adjustment specification *AS* records using information provided on *FA*, *RS*, and *SC* records and/or as specified by adjustment equation *EQ* records. The *EQ*, *AS*, *FA*, *RS*, and *SC* records are input in either the HIN and/or FLO file as specified by JC(3) in *JC* record field 7.

**Fields 8 and 9:** With JC(1) and JC(2) option 7, the FLOW and EP arrays are initially filled with data read from the *SIM* output OUT file (*HYD* input file with filename root1.OUT file). Variables read by *HYD* from the OUT file are listed in Table 3.1. JC(4) and JC(5) in *JC* record fields 8 and 9 control the choice of which variables are selected to initially populate the FLOW and EP arrays.

**Field 10:** *SIM* options allow the OUT file to be written as a formatted text file or unformatted binary file, with the default being a text file. JC(6) tells *HYD* which type of OUT input file it is opening. JC(6) also serves to open the OUT input file for *AS* record applications even when it is not already being opened for JC(1) or JC(2) option 7 or *OI* records. The root1.OUT file is opened by either JC(1) or JC(2) option 7, one or more *OI* records, or a non-zero entry for JC(6) in *JC* record field 10. Any time the root1.OUT file is opened, all of the variables listed in Table 3.1 are read and stored. The file is opened only once with all *JC*, *OI*, and *AS* record applications of its data having access.

**Field 11:** Methods for distributing flows from gaged (known flow) to ungaged (unknown flow) control points are identical in *SIM* and *HYD* and are described in *Reference Manual* Chapter 3. The choice of flow distribution method is controlled by INMETHOD in *CP* record field 6. INMETHOD options 3 through 8 require data from a DIS file. If INMETHOD in *CP* record field 6 is greater than 2 for one or more control points, a DIS file must be opened by parameter JC(7) in *JC* record field 11. The Fortran subroutines that perform the flow distribution computations are essentially identical in *HYD* and *SIM*.

**Fields 12 and 13:** Options defining the format of the output files in which stream flows and evaporation-precipitation depths are recorded are controlled by JC(8) and JC(9). JC(8) and JC(9) specify the use of either FLO and/or EVA, DSS, or HOT files to store the final values in the

FLOW(cp,year,month) and EP(cp,year,month) arrays. JC(8) option 7 allowing the identifier *RU* to be placed on records in the HOT file is designed to facilitate development of a *SIM* input RUF file.

**Field 14:** Assuming a DIS file is activated by JC(7) in field 11, JC(10) in field 14 allows two types of optional tables of watershed parameters to be created in the root2.HOT file. The flow distribution computations can be accomplished without summarizing the watershed parameters in these tables. The tables provide general information that may be of interest to the model user.

**Field 15:** RS(6) on the *RS* record creates a table in the HOT file summarizing the adjustments associated with a reservoir. The RS(6) parameter must be activated on the *RS* record of each individual reservoir for which a table is to be created. JC(11) in *JC* record field 15 opens the HOT file for this purpose. If the HOT file is opened anyway by other parameters, JC(11) is unnecessary.

**Fields 16 and 17:** *JC* record fields 15 and 16 are the same as *SIM JD* record fields 8 and 9 except ADJINC options 4 and 5 performed within the *SIM* simulation are not relevant in *HYD*. The subroutine that computes the incremental flow adjustments is identical in *HYD* and *SIM*. Negative incremental flow options are described in Chapter 3 of the *Reference Manual* [1].

**Field 18:** Options for adjusting evaporation-precipitation depths for runoff at the reservoir site are the same in *HYD* and *SIM* and are described in Chapter 3 of the *Reference Manual* [1]. Options are specified by *CP* record field 9 with the EPADJ default set by *JD* record field 10 in *SIM* and *JC* record field 17 in *HYD*.

**Fields 19 and 20:** The Hydrologic Engineering Center (HEC) Data Storage System (DSS) is described in Chapter 6 of the *Users Manual* [2] and discussed throughout the other WRAP manuals. Routines from a HEC-DSS library are incorporated into the *SIM*, *TABLES*, and *HYD* programs allowing creation of and access to DSS files. The same type of DSS information provided in *JC* record fields 19 and 20 for *HYD* is entered on the *OF* record for *SIM* and the *FILE* record for *TABLES*. JC(1), JC(2), JC(3), and JC(4) record options control the use of DSS files with *HYD* to store stream flow and evaporation-precipitation data.

**Field 19:** The HEC-DSS library routines incorporated into the WRAP programs create a variety of different types of trace and error messages. A parameter sets the level of messages to be written to the message file as outlined in *Reference Manual* Chapter 7. JC(12) sets the level of DSS trace and error messages written to the HMS file.

**Field 20:** Dates are included in the pathnames that label DSS time series data records. Field 20 provides a label for the first month of the time series data in the DSS file. If field 20 is blank, JAN for January is adopted by default.

**Field 21:** CDO is an optional record identifier that is used instead of a CD of *IN* on output records written to the FLO and HOT files. CDO can also be used on input records in a FLO file. For example, if FA entered in field 21, all records created by *HYD* in its FLO or HOT output files, that would otherwise begin with the record identifier *IN*, will instead begin with *FA*. *IN* is replaced by *FA*. *HYD* could read either *IN* or *FA* records or both from the FLO input file.

## XL Record – Multiplication Factors and Parameter Limits

field	columns	variable	format	value	description
1	1-2	CD	A2	XL	Record identifier
<u><i>Multiplication Factors Applied to Input Data</i></u>					
2	3-8	STX	F6.0	+	Multiplier of reservoir storage volumes on <i>WS</i> , <i>OR</i> , <i>SV</i> , <i>PV</i> , <i>MS</i> , and <i>IS</i> records. Blank, 0 Default = 1.0
3	9-16	INX	F8.0	+	Multiplier of flows on <i>IN</i> records, subject to being superseded by non-blank <i>CP</i> record field 4. Blank, 0 Default = 1.0
4	17-24	EVX	F8.0	+	Multiplier of E-P rates on <i>EV</i> records, subject to being superseded by non-blank <i>CP</i> record field 5. Blank, 0 Default = 1.0
5	25-32	CIX	F8.0	+	Multiplier of flows on <i>CI</i> records. Blank, 0 Default = 1.0
6	33-40	SAX	F8.0	+	Multiplier of reservoir surface areas on <i>SA</i> records. Blank, 0 Default = 1.0
<u><i>Multiplication Factors Used in Computations</i></u>					
7	41-48		8x	not read by HYD	Multiplier factor for hydropower computations used in <i>SIM</i> but not used in <i>HYD</i> .
8	49-56	DEPTHX	F8.0	+	Multiplier factor for runoff depth in NRCS CN method flow distribution computations. Blank, 0 Default = 0.01875 (Reference Manual Chapter 3)
<u><i>Limits on CN and Mean Precipitation</i></u>					
9	57-64	CNLB	F8.0	+	Lower limit on CN (Reference Manual Chapter 3) Blank, 0 Default = 0.0
10	65-72	CNUB	F8.0	+	Upper limit on CN Blank, 0 Default = 100.0
11	73-80	MPLB	F8.0	+	Lower limit on MP Blank, 0 Default = 0.0
12	81-88	MPUB	F8.0	+	Upper limit on MP Blank, 0 Default = 100 inches or other rainfall unit in effect
<u><i>Warning Limit on Runoff EP-Adjustment</i></u>					
13	89-96	EPWL	F8.0	+	Limit for warning message (Reference Manual Ch 3) Blank, 0 Default = 2.0 feet or other depth unit in effect

The *XL* record is identical in *HYD* and *SIM* with the exception of the *SIM* hydropower factor in field 7 which serves no purpose in *HYD*.

## CP Record – Control Point Information

field	columns	variable	format	value	description
1	1-2	CD	A2	CP	Record identifier
2	3-8	CPID(cp,1)	A6	AN	Control point identifier [cp = 1,NCPTS]
3	11-16	CPID(cp,2)	2x,A6	AN	Identifier of next downstream control point. Blank,OUT Basin outlet. There is no control point downstream.
<u>Multiplier Factors</u>					
4	17-24	CPDT(cp,1)	F8.0	blank,0 + –	Default factor = 1.0 Factor by which inflows on <i>IN</i> records are multiplied. Monthly factors on following MF record are applied.
5	25-32	CPDT(cp,2)	F8.0	blank,0 + –	Default factor = 1.0 Factor by which net evaporation rates are multiplied. Monthly factors on following MF record are applied.
<u>Do Not Include IN/EV Records in Output</u>					
6	36	INEV(cp)	I4	1 2 3 4 5	Omit the <i>IN</i> records for this CP in the output file. Omit the <i>EV</i> records for this CP in the output file. Omit both the <i>IN</i> and <i>EV</i> records in the output file. Omit both for this CP and all previous control points. Omit for this CP and all subsequent control points.
<u>Method for Obtaining Naturalized Flows</u>					
7	40	INMETHOD (cp)	I4	0,1 2 3 4 5 6 7 8 10	<i>IN</i> records are input for this control point. Specifications are provided by <i>CPIN(cp)</i> in field 7. Distribution equation with <i>FC</i> record coefficients. NRCS CN method with flow limit. NRCS CN method without flow limit. Channel loss coefficient with DAR method. Drainage area ratio method (areas from <i>WP</i> records). NRCS method with channel losses. Equation proportioning flows at other control points.
8	43-48	CPIN(cp)	2x,A6	blank AN NONE ZERO	INMETHOD in field 6 is not 2. Another CP from which <i>IN</i> records are repeated. The words <i>none</i> , <i>zero</i> , <i>NONE</i> , or <i>ZERO</i> indicate zero stream flows at this control point.
<u>Method for Obtaining Net Evaporation-Precipitation</u>					
9	51-56	CPEV(cp)	2x,A6	blank AN NONE ZERO	<i>EV</i> records are read as input. Another CP from which <i>EV</i> records are repeated. The words <i>none</i> , <i>zero</i> , <i>NONE</i> , or <i>ZERO</i> in this field indicate zero net evaporation at this control point.
<u>EP Adjustment for Runoff from Reservoir Site</u>					
10	57-64	EWA(cp)	F8.0	blank,0 –1.0 –2.0 –3.0, <–3.0 +	Default set by <i>JC</i> record field 16 is used. Ungaged CP from <i>FD</i> record field 3 is used. Gaged CP from <i>FD</i> record field 3 is used. No adjustment. Overrides blank <i>JC</i> field 16. Watershed area in acres for runoff adjustment.

## CP Record – Control Point Information (Continued)

field	columns	variable	format	value	description
<i>Channel Loss Factor</i>					
11	65-72	CL(cp)	F8.0	+ blank	Channel loss factor for stream reach below CP. The default channel loss factor value is 0.0.
<i>Watershed Areas on WP Records</i>					
12	80	INWS(cp)	I8	blank,0 +	Parameters on WP record are for the total watershed. WP record parameters for incremental watersheds.

The set of all *CP* records follows the *JC* and *XL* records in the HIN file. The *CP* record has the same format for either *HYD* or *SIM* except the *HYD CP* record has the parameter INEV(cp) added as *CP* record field 6 and the addition of a *MF* record as an extension of the *CP* record.

*CP* records control some of the *HYD* computations and provide information required for other *HYD* computations. *CP* records for all control points are required to support essentially all *HYD* operations except those activated by *OI* records. The *OI* record needs no information from *CP* records and does not reference *CP* records. The other input records use the ordering provided by CPID(cp,1) in *CP* record field 1. Computations are performed and output written in the control point sequence in which *CP* records are read from the HIN file. *AS* record cascading operations require CPID(cp,2) provided in *CP* record field 3. All fields of the *CP* record except fields 1 and 2 (CD and CPID(cp,1)) may be left blank unless specifically needed.

The FLOW(cp,year,month) and EP(cp,year,month) arrays are multiplied by CPDT(cp,1) and CPDT(cp,2) from *CP* record fields 4 and 5 which have defaults of 1.0 as the stream flow and evaporation-precipitation data are initially read from FLO, EVA, HYD, or DSS files.

Flows are distributed from gaged (known flow) to ungaged (unknown flow) control points based either on CPDT(cp,1) and/or CPIN(cp) specified in *CP* record fields 4 and 8 or INMETHOD from *CP* record field 7. If INMETHOD is greater than 2 for one or more control points, a flow distribution file must be activated (opened) with JC(7) in *JC* record field 11.

Flow adjustments controlled by *AS* records require the next downstream control point identifier entered in *CP* record field 3 for each control point to define system connectivity for the cascading computations. The channel loss factors used in cascading flow adjustments downstream are provided in field 10 of the *CP* records.

*CP* records are used for *EP* and *AN* record operations to sequence the control points. Each control point (or reservoir) identifier referenced by *EP* and *AN* records must be found in field 2 of one of the *CP* records. The EP(cp or reservoir,year,month) array upon which the *EP* and *AN* records operate may be populated from the OUTRES(reservoir,year,month) array from the OUT file in which data are referenced by reservoir rather than control point. With only *JC*, *EP*, *AN*, and *CP* records in the HIN file, the identifiers in *CP* record field 2 may be reservoir identifiers.

## MF Record – Monthly Factors

field	columns	variable	format	Value	description
1	1-2	CD	A2	MF	Record identifier.
2	3-8	MF	F6.0	+	Factors for each of 12 months.
3-13	9-96	MF	F8.0	+	

Control point *CP* record fields 4 and 5 are multiplier factors for all stream flows and all evaporation-precipitation depths  $FLOW(cp, year, month)$  and  $EP(cp, year, month)$  for that control point. The *MF* record expands this capability. A negative number for  $CPDT(cp, 1)$  or  $CPDT(cp, 2)$  indicates that the *CP* record will be followed by a *MF* record with a set of 12 numbers. The 12 monthly factors on the *MF* record are applied as specified in *CP* record fields 4 and 5 as follows.

For  $CPDT(cp, 1)$  or  $CPDT(cp, 2)$  of  $-2.0$ , flows or evaporation depths are multiplied by the *MF* record factors.

For  $CPDT(cp, 1)$  or  $CPDT(cp, 2)$  of  $-3.0$ , *MF* record factors are added to flows or evaporation depths.

For  $CPDT(cp, 1)$  or  $CPDT(cp, 2)$  of  $-4.0$ , the operation and factors specified for the preceding control point are repeated for this control point.

### Sequencing of Records in HIN File

The HIN file record sequencing is based on dividing record types into the following groups.

- The HIN file begins with a required *JC* record followed by optional *XL* record.
- The *JC* and *XL* records are followed by the set of all *CP/MF* records, followed by the set of all *CI* records, followed by the set of all pairs of *SV/SA* records. The *CP*, *CI*, *SV*, and *SA* records are essentially the same in *HYD* and *SIM* and are sequenced the same in the *HYD* HIN file and *SIM* DAT file.
- Any number of *OI*, *EP*, and *AN* records are grouped together in any order in the HIN file. The *OI*, *EP*, and *AN* records must be grouped together in one group, but individual records can be placed in any order within the group. The set of all *OI*, *EP*, and *AN* records follows after the *CP/MF*, *CI*, and *SV/SA* records.
- The *EQ*, *AS*, *FA*, *RS*, and *SC* records comprise a group of sets of input records that are placed as the last records in either the HIN file and/or FLO file as specified by *JC*(3) from the *JC* record. The HIN file always ends with an *ED* record. The set of *EQ*, *AS*, *FA*, *RS*, and *SC* records ends with an *ED* record in either the HIN or FLO files.

### CI Record – Constant Inflows and/or Outflows (12 monthly flows per record)

field	columns	variable	format	value	description
1	1-2	CD	A2	CI	Record identifier.
2	3-8	CIID	A6	AN	Control point identifier.
3-14	9-104	CI(M=1,12)	12F8.0	+,–	Flow added to naturalized flow at control point CIID for month M.

The set of all *CI* records follows the set of all *CP* records in *HYD* just like in *SIM*. The *CI* record format is identical in both *HYD* and *SIM*. Flows on *CI* records are added to the stream flows at the specified control point and, with adjustments for channel losses, at all downstream control points. Addition and cascading of the 12 monthly flows is repeated in each year.

Any number of optional *CI* records may be entered for any control point in any order. Two alternative *CI* record formats include 12 monthly flows on either one record or two records.

### CI Records – Constant Inflows and/or Outflows (two records with six monthly flows each)

#### First CI Record – Constant Inflows and/or Outflows for Months 1-6

field	columns	variable	format	value	description
1	1-2	CD	A2	UC	Record identifier.
2	3-8	CIID	A6	AN	Control point identifier.
3-8	9-56	CI(M=1,6)	6F8.0	+	Monthly flows for months 1-6. Six flows are entered on each of two CI records.

#### Second CI Record – Constant Inflows and/or Outflows for Months 7 through 12

field	columns	variable	format	value	description
1	1-2	CD	A2	UC	Record identifier.
2	3-8		6x		Field 2 of second record is not used.
3-8	9-56	CI(M=7,12)	6F8.0	+	Monthly flows for months 7-12. Six flows are entered on each of two CI records.

### **SV** Record – Storage Volumes for Reservoir Storage versus Area Table

field	columns	variable	format	value	description
1	1-2	CD	A2	SV	Record identifier.
2	3-8	RES	A6	AN	Reservoir identifier.
3-27	9-208	TARA(I) I=1,25	12F8.0	+	Reservoir storage volumes corresponding to surface areas in same fields of the following SA record.

### **SA** Record – Surface Areas for Reservoir Storage versus Area Table

field	columns	variable	format	value	description
1	1-2	CD	A2	SA	Record identifier.
2	3-8	RES	6x		Field not used.
3-27	9-208	TARB(I) I=1,25	12F8.0	+	Reservoir surface areas corresponding to storage volumes in same fields of the preceding SV record.

The set of all pairs of *SV* and *SA* records follows the set of all *CI* records which follows the set of all *CP* records in the HIN file. *SV* and *SA* records are the same in both *HYD* and *SIM*. A reservoir storage-area relationship may be defined optionally with a pair of *SV-SA* records or by equation coefficients provided on the *AS* record in *HYD* or *WS* record in *SIM*.

The reservoir surface area versus storage volume relationships are used solely for computing net evaporation-precipitation volumes. Within the *HYD* computational routines, for given beginning-of-month and end-of-month storage volumes, the water surface area determined by linear interpolation of the storage volume (*SV* record) versus surface area (*SA* record) table is combined with a net evaporation-precipitation to obtain a monthly volume.

The *SV* and *SA* records have the same format. The *SV-SA* tables are allowed a maximum of 25 pairs of values. A *SV* record must be followed by the corresponding *SA* record. A complete set of all *SV-SA* records are grouped together in the HIN file.

## OI Record – SIM Output OUT File Data Written to HYD Output HOT File

field	columns	variable	format	value	description
1	1-2	CD	A2	OI	Record identifier.
<u>Variable Read from OUT File</u>					
2	8	OVAR(I)	I6	1	Naturalized flows from control point output (NAT).
	I = 1 to total			2	Regulated flows from control point output (REG).
	number of OI records			3	Unappropriated flows from control point (UNA).
				4	Stream flow depletions from control point (DEP).
				5	Return flows from control point output (RFR).
				6	Diversion targets from control point output (TAR)
				7	Diversions at control point (DIV = TAR – SHT)
				8	Diversion shortage from control point output (SHT)
				9	Stream flow depletions for water right (DEP).
				10	Return flows for water right output records (RFL).
				–10	HYD shifts return flows (RFL) forward one month.
				11	Diversions for WR or releases for IF right (DIV).
				12	End-of-month reservoir storage volume (STO)
				13	Reservoir storage capacity (RSC)
				14	Reservoir storage drawdown ( RSD = RSC – STO )
				15	Evap-precip depths before runoff adjustments (EVR).
				16	Evap-precip depths after runoff adjustments (EPD).
				17	Instream flow target (IFT) for IF record water right.
				18	Instream flow target (IFT) from control point output.
<u>Specifications for Records Written to HOT File</u>					
3	12	OG(I)	I4	blank,0,1	Output records are grouped with all cps for each year.
				2	Output grouped with all years for each control point.
4	15-16	OCD(I)	2x,A2	blank	First two characters blank with no record identifier.
				AN	Record identifier written as the first two characters.
5	20	OCP(I)	I4	blank, 0	Control point or reservoir identifier or first 6 characters of water right identifier from OUT file is adopted.
				1	Identifier specified in field 6 below is adopted for the output record written to the HOT file records.
6	23-28	OUID(I)	2x,A6	AN	Identifier included in output record written to HOT file which may be blank or contain up to six characters.
<u>Selection of Control Points, Reservoirs, or Rights</u>					
7	29-36	OID(I)	2x,A6	Blank, 0	All control points or reservoirs in OUT file.
				AN	Control point identifier for OVAR=1,2,3,4,5,6,7,8,18
					Reservoir identifier for OVAR=12,13,14,15,16,17
8	37-52	OWRID (I)	A16	Blank, 0	Records are created for all water rights in OUT file.
				AN	Water right identifier for OVAR = 9, 10, 11, or 17.

The OI record is designed for converting SIM simulation results to records in a SIM or HYD input file. OI records allow data read from a SIM output OUT file (HYD root1.OUT input file) to be written directly to the HYD output HOT file (root2.HOT). No computations are performed to

modify the data, and no other *HYD* input records other than the *JC* record are needed. The data are written to the root2.HOT file in the same standard format as *IN* and *EV* records, but the identifiers are for either control points, reservoirs, or water rights depending on the variable, and the optional record identifier in the first two fields of each record is specified in *OI* field 4.

### **Explanation of OI Record Fields**

**Field 2:** The variable (OVAR in field 2) to be written as records in the *HYD* output file with filename root2.HOT is selected from the list.

OVAR option 10 refers to return flows (RFL) associated with a water right. *SIM* includes a next-month return flow option in which the return flows reenter the river system in the month after the diversion. OVAR option -10 consists of shifting the return flows to the next month.

Water right *WR* record diversions and instream flow *IF* record reservoir releases (DIV) selected with OVAR options 7 or 11 are determined by subtracting shortages (SHT) from targets (TAR).

Reservoir storage drawdown selected with OVAR option 14 are determined by subtracting storage volume (STO) from storage capacity (RSC). This option is designed for use with observed reservoir storage contents, represented by the reservoir storage capacity (RSC) quantity recorded by *SIM* on reservoir/hydropower output records in the OUT file, which are provided as input in the *SIM* DAT file with monthly storage *MS* and observed storage *OS* records.

**Field 3:** With the default OG option 1, the records written to the file with filename root2.HOT file are grouped by year. Records for all control points for a year are followed by a complete set of records for all control points for the next year, and so forth. With option 2, records all years for a particular control point are followed by the set of records for all years for the next control point. With either option, each record contains 12 values for the 12 months of the year.

**Field 4:** OCD is a two-character record identifier such as IN, EV, FA, TS, or any other two characters. With field 4 left blank, no record identifier is assigned and the first two characters of the record are blank.

**Fields 5 and 6:** A six-character identifier is written in the second field containing columns 3-8 of the output records written to the HOT file. The identifier will typically identify a control point, reservoir, or water right. If field 5 is blank, the control point (VAR = 1, 2, 3, 4, or 5) or reservoir (VAR = 9 or 10) identifier or first six characters of the water right (VAR = 6, 7, 8) identifier from the OUT file is recorded in the records written to the HOT file. An integer 1 in field 5 indicates that an identifier entered in field 6 is to be written in the output records. A 1 in field 5 and blank field 6 results in the identifier field being blank in the output records written to the HOT file.

**Fields 7 and 8:** Depending on the variable selected in field 2, the data is for either control points (VAR = 1, 2, 3, 4, or 5), water rights (VAR = 6, 7, 8), or reservoirs (VAR = 9 or 10). Parameter OID in field 5 or OWRID in field 6 allows reading of either one control point, one reservoir, or one water right or all control points, all reservoirs, or all water rights found in the OUT input file. A blank field 7 or 8 defaults to all.

## EP Record – Evaporation-Precipitation Combining Specifications

field	columns	variable	format	value	description
1	1-2	CD	A2	EP	Record identifier
2	3-8	ID	A6	AN	Control point or reservoir identifier
3	11-16	EPID(I,1)	2x,A6	AN	Control point or reservoir identifier
4	17-24	EPM(I,1)	F8.0	+	Multiplier
5	27-32	EPID(I,2)	2x,A6	AN	Control point or reservoir identifier
6	33-40	EPM(I,2)	F8.0	+	Multiplier
7	43-48	EPID(I,3)	2x,A6	AN	Control point or reservoir identifier
8	49-56	EPM(I,3)	F8.0	+	Multiplier
9	59-64	EPID(I,4)	2x,A6	AN	Control point or reservoir identifier
10	75-72	EPM(I,4)	F8.0	+	Multiplier

I = 1 to total number of *EP* records

The monthly evaporation depths, precipitation depths, or net evaporation-precipitation depths for the control point or reservoir identified in *EP* record field 2 are computed as a weighted average of the values read for the control points identified in *EP* record fields 3, 5, 7, and 9 using the multipliers from fields 4, 6, 8, and 10. This averaging operation is performed on the relevant values in the EP(cp or res, year, month) array. The resulting computed depths are recorded back into the EP(cp or res, year, month) array. Thus, known depths at some control points or reservoirs are used to compute depths at other control points or reservoirs. Depths may also be changed at the same control point or reservoir.

*EP* and *AN* record operations reference the identifiers in *CP* record field 2 for sequencing purposes. The EP(cp or res,year,month) array upon which the *EP* and *AN* records operate may be populated from the OUTRES(res,year,month) array read from the OUT file in which data are referenced by reservoir rather than control point. With only *JC*, *EP*, *AN*, and *CP* record operations activated in the HIN file, the identifiers in *CP* record field 2 may be reservoir identifiers. However, the *EP* record can not be used with OUT file data referenced to reservoirs with *CP* records referenced to control points. All fields other than fields 1 and 2 (CD and CPID(cp,1)) on the CP record may be left blank if not needed.

## AN Record – Year of Monthly Stream Flow Volumes or Evaporation-Precipitation Depths

field	columns	variable	format	value	description
1	1-2	CD	A2	AN	Record identifier
2	3-8	ID	2x,A6	blank AN	All control points (or all reservoirs). Control point identifier (or reservoir identifier).
3	12	AN(I,1)	I4	blank,0,1 2	Monthly stream flow volumes. Monthly evaporation-precipitation depths.
4	16	AN(I,2)	I4	blank,0,1 2 3	Compute means for each of the 12 months of year. Adopt exceedance frequency from field 5 below. Adopt the 12 amounts from the following AN record.
5	17-24	ANF(I)	F8.0	+	Exceedance frequency as percent for option 2 above.
<u>Output or Results</u>					
6	28	AN(I,3)	I4	blank,0,1 2 3	IN or EV records to HOT file (with replacement). IN or EV records to HOT file (without replacement). Stored in FLOW or EP array.
<u>Time Span Covered by New Data</u>					
7	29-36	AN(I,4)	I8	blank, +	First year of data created. Default = YRST from JC
8	37-44	AN(I,5)	I8	blank, +	Last year of data created. Default=YRST+NYRS-1
<u>Time Span for Mean or Frequency Computations</u>					
9	45-52	AN(I,6)	I8	blank, +	First year. Default is YRST in JC record field 2.
10	53-60	AN(I,7)	I8	blank, +	Last year. Default = YRST + NYRS - 1
I = 1 to total number of AN records					

## AN Record – Supplemental Second AN Record for AN Record Field 4 AN(I,2) Option 3

field	columns	variable	format	value	description
1	1-2	CD	A2	AN	Record identifier
2	3-8	ID	6x	blank	Field is not read.
3	9-16	ANA(I,1)	F8.0	+	Flow volume or evap-precip depth for month 1 (Jan)
4	17-24	ANA(I,2)	F8.0	+	Flow volume or evap-precip depth for month 2 (Feb)
5	25-32	ANA(I,3)	F8.0	+	Flow volume or evap-precip depth for month 3 (Mar)
6	33-40	ANA(I,4)	F8.0	+	Flow volume or evap-precip depth for month 4 (Apr)
7	41-48	ANA(I,5)	F8.0	+	Flow volume or evap-precip depth for month 5 (May)
8	49-56	ANA(I,6)	F8.0	+	Flow volume or evap-precip depth for month 6 (Jun)
9	57-64	ANA(I,7)	F8.0	+	Flow volume or evap-precip depth for month 7 (Jul)
10	65-72	ANA(I,8)	F8.0	+	Flow volume or evap-precip depth for month 8 (Aug)
11	73-80	ANA(I,9)	F8.0	+	Flow volume or evap-precip depth for month 9 (Sep)
12	81-88	ANA(I,10)	F8.0	+	Flow volume or evap-precip depth in month 10 (Oct)
13	80-96	ANA(I,11)	F8.0	+	Flow volume or evap-precip depth in month 11 (Nov)
14	97-104	ANA(I,12)	F8.0	+	Flow volume or evap-precip depth in month 12 (Dec)

### **Explanation of AN Record Fields**

*AN* records are designed to create sets of 12 stream flow volumes or evaporation-precipitation depths at each pertinent control point. These sets of 12 monthly values can be repeated without change for multiple years to either create a new set of *IN* and/or *EV* records or to extend the number of years covered by a dataset. For example, using AN(I,2) option 1 in *AN* record field 4, a set of mean evaporation-precipitation rates may be computed from period-of-record data in the *EP* array to cover years not included in the record. Using AN(I,2) option 2, a flow dataset may be developed based on computing flows for each of the 12 months of the years that are equaled or exceeded during a specified percentage of the years in the *FLOW* array.

**Field 2:** The computations are repeated by control point for all the control points included in the *FLOW* or *EP* array (as defined by *CP* records) if *AN* record field 2 is blank. Entering a control point identifier in field 2 results in the computations being limited to just that control point. Reservoir identifiers may be substituted for *CP* identifiers. However, the *AN* record field 2 ID must match an identifier in field 2 of a *CP* record, since the *CP* record identifiers control referencing in the *FLOW*(cp,year,month) and *EP*(cp or reservoir,year,month) arrays.

**Field 3:** The operations may be performed with either *FLOW*(cp,year,month) array monthly stream flow volumes or *EP*(cp or reservoir,year,month) array evaporation-precipitation rates.

**Fields 4, 9, 10:** Three alternative options are available for creating the sets of 12 monthly values. The first two options use 12 data sets, one set for each of the months January through December, for the years defined by AN(I,6) and AN(I,7) in *AN* fields 9-10 with defaults from *JC* fields 2-3. Option 1 consists of computing the means for each month. Option 2 consists of determining the monthly volume or depth amount that is equaled or exceeded during ANF(I) percentage of years specified in field 5. Option 3 consists of entering a set of 12 values on an extra *AN* record placed behind this record. The second auxiliary *AN* record is entered only for AN(I,3) option 3.

**Field 5:** The exceedance frequency ANF(I) is used only if AN(I,3) option 2 is selected in field 4. The frequency is expressed as a percentage. With 25.0 entered for ANF(I), a January flow amount is determined that is equaled or exceeded during 25.0 percent of the years of data taken from the *FLOW* array for the period from AN(I,6) through AN(I,7). Flows are sorted. If no number of years corresponds to exactly 25.0 percent of the total number of years, linear interpolation is applied to the two January flow volumes that bracket the 25.0 percent value.

**Fields 6, 7, 8:** Field 6 controls the placement of the results of the *AN* record computations. Fields 7 and 8 define the span of years over which the one year of computed monthly flows or depths is repeated in the output. Field 6 options 1 and 2 consist of writing the final dataset developed by the *AN* record to the *HOT* file as a set of *IN* or *EV* records. The difference between options 1 versus 2 is relevant only if the period defined by *AN* fields 7 and 8 overlaps the period covered by the *FLOW* and *EP* arrays as defined by *JC* fields 2 and 3. With *AN* field 6 option 1, the new data is repeated for all years defined by the *AN* record fields 7 and 8, even though this may result in existing *FLOW* or *EP* array data being replaced. With option 2, the original data from the *FLOW* or *EP* array is adopted for the period of years defined by *JC* record fields 2 and 3, and the new synthesized data is repeated for all other years spanning the period defined by *AN* record fields 7 and 8. *JC* field 6 option 3 consists of storing the computed data in the *FLOW* or *EP* array. All *AN* fields 7 and 8 years falling within the *JC* fields 2 and 3 period are covered.

## **IN and EV Records in Standard Default Format**

### **IN Record – Inflows or Naturalized Stream Flows at a Control Point**

field	columns	variable	format	value	description
1	1-2	CD	A2	IN	Record identifier
2	3-8	ID	A6	AN	Control point identifier
3	9-12	NYR	I4	+	First year for an <i>IN</i> record repeated for multiple years
				blank,0	<i>IN</i> record is for one year only; it is not repeated
4	13-16	PYR	I4	+	Year (last year to repeat if field 3 is not zero or blank)
5	17-24	INFLOW(cp,1)	F8.0	+	Naturalized stream flow for month 1
6	25-32	INFLOW(cp,2)	F8.0	+	Naturalized stream flow for month 2
7	33-40	INFLOW(cp,3)	F8.0	+	Naturalized stream flow for month 3
8	41-48	INFLOW(cp,4)	F8.0	+	Naturalized stream flow for month 4
9	49-56	INFLOW(cp,5)	F8.0	+	Naturalized stream flow for month 5
10	57-64	INFLOW(cp,6)	F8.0	+	Naturalized stream flow for month 6
11	65-72	INFLOW(cp,7)	F8.0	+	Naturalized stream flow for month 7
12	73-80	INFLOW(cp,8)	F8.0	+	Naturalized stream flow for month 8
13	81-88	INFLOW(cp,9)	F8.0	+	Naturalized stream flow for month 9
14	89-96	INFLOW(c,10)	F8.0	+	Naturalized stream flow for month 10
15	97-104	INFLOW(c,11)	F8.0	+	Naturalized stream flow for month 11
16	105-112	INFLOW(c,12)	F8.0	+	Naturalized stream flow for month 12

### **EV Record – Evaporation, Precipitation, or Net Evaporation-Precipitation Rates**

field	columns	variable	format	value	description
1	1-2	CD	A2	IN	Record identifier
2	3-8	ID	A6	AN	Control point identifier
3	9-12	NYR	I4	+	First year for an <i>EV</i> repeated for multiple years
				blank,0	<i>EV</i> record is for one year only; it is not repeated
4	13-16	PYR	I4	+	Year (last year to repeat if field 3 is not zero or blank)
5	17-24	EVAPR(cp,1)	F8.0	+	Net evaporation-precipitation for month 1
6	25-32	EVAPR(cp,2)	F8.0	+	Net evaporation-precipitation for month 2
7	33-40	EVAPR(cp,3)	F8.0	+	Net evaporation-precipitation for month 3
8	41-48	EVAPR(cp,4)	F8.0	+	Net evaporation-precipitation for month 4
9	49-56	EVAPR(cp,5)	F8.0	+	Net evaporation-precipitation for month 5
10	57-64	EVAPR(cp,6)	F8.0	+	Net evaporation-precipitation for month 6
11	65-72	EVAPR(cp,7)	F8.0	+	Net evaporation-precipitation for month 7
12	73-80	EVAPR(cp,8)	F8.0	+	Net evaporation-precipitation for month 8
13	81-88	EVAPR(cp,9)	F8.0	+	Net evaporation-precipitation for month 9
14	89-96	EVAPR(c,10)	F8.0	+	Net evaporation-precipitation for month 10
15	97-104	EVAPR(c,11)	F8.0	+	Net evaporation-precipitation for month 11
16	105-112	EVAPR(c,12)	F8.0	+	Net evaporation-precipitation for month 12

## **IN and EV Records in HYD File Format**

Earlier *WRAP2/WRAP3* versions of *WRAP* used a format, now specified as Option 3 in *JC* record fields 5 and 6, with *IN* and *EV* records with six months per record stored in a *HYD* file (filename extension *HYD*). *IN* records for all control points for a year are followed by a corresponding set of *EV* records. *IN/EV* records for all control points are grouped together by year. All the records for a year are followed by a complete set of records for the next year.

### **First IN Record for Each Year – Inflows**

field	columns	variable	format	value	description
1	1-2	CD	A2	IN	Record identifier
2	3-8	ID	A6	AN	Control point identifier
3	9-16	PYR	I8	+	Year
4	17-24	Q(1)	F8.0	+	Naturalized stream flow for month 1
5	25-32	Q(2)	F8.0	+	Naturalized stream flow for month 2
6	33-40	Q(3)	F8.0	+	Naturalized stream flow for month 3
7	41-48	Q(4)	F8.0	+	Naturalized stream flow for month 4
8	49-56	Q(5)	F8.0	+	Naturalized stream flow for month 5
9	57-64	Q(6)	F8.0	+	Naturalized stream flow for month 6

### **Second IN Record for Each Year – Inflows**

field	columns	variable	format	value	description
1	1-2	CD	A2	IN	Record identifier
2	3-8		6X		not used
3	9-16		8X		not used
4	17-24	Q(7)	F8.0	+	Naturalized stream flow for month 7
5	25-32	Q(8)	F8.0	+	Naturalized stream flow for month 8
6	33-40	Q(9)	F8.0	+	Naturalized stream flow for month 9
7	41-48	Q(10)	F8.0	+	Naturalized stream flow for month 10
8	49-56	Q(11)	F8.0	+	Naturalized stream flow for month 11
9	57-64	Q(12)	F8.0	+	Naturalized stream flow for month 12

### **First EV Record for Each Year – Reservoir Evaporation-Precipitation Rates**

field	columns	variable	format	value	description
1	1-2	CD	A2	EV	Record identifier
2	3-8	ID	A6	AN	Control point identifier
3	9-16	PYR	I8	+	Year
4	17-24	EV(1)	F8.0	+	Reservoir evaporation-precipitation rate for month 1
5	25-32	EV(2)	F8.0	+	Reservoir evaporation-precipitation rate for month 2
6	33-40	EV(3)	F8.0	+	Reservoir evaporation-precipitation rate for month 3
7	41-48	EV(4)	F8.0	+	Reservoir evaporation-precipitation rate for month 4
8	49-56	EV(5)	F8.0	+	Reservoir evaporation-precipitation rate for month 5
9	57-64	EV(6)	F8.0	+	Reservoir evaporation-precipitation rate for month 6

### **Second EV Record for Each Year – Same format as indicated above.**

### Alternative Formats for IN and EV Records

The content and organization of *IN* and *EV* records are the same in both programs *HYD* and *SIM*. Sequences of monthly stream flow volumes representing inflows to the river/reservoir system are entered on inflow *IN* records. The stream flows are typically naturalized flows but may represent other specified conditions of river basin development. Sequences of monthly reservoir surface net evaporation less precipitation depths are entered on evaporation *EV* records. The *IN* and *EV* records are organized by year and control point. The ordering of control points must be consistent for all of the years of *IN* records and *EV* records but is otherwise arbitrary. The years must be in chronological order starting with the earliest year and ending with the last.

Field 3 of the *IN* and *EV* records contains the variable *NYR* (first year) which signals the program to repeat the 12 monthly values on the record from the year *NYR* (field 3) through the year *PYR* (field 4). If field 3 is blank or zero, the *IN* or *EV* record represents only one year. If records are not repeated for multiple years, field 4 (*PYR*) may also be left blank after the first year since the records must be in chronological sequence. An error check confirms that any years entered are in the correct chronological sequence, but zeros (blanks) are ignored.

Parameters on the *JC* record specify the manner in which the *IN* and *EV* records are organized. The standard default set of input files include a *FLO* file for storing *IN* records and a *EVA* file for storing *EV* records. Optionally, program *HYD* will also read *EV* and *IN* records in a file with filename extension *HYD* in a format adopted in early versions of *WRAP*. The default record format and file organization are described first followed by a description of the old approach still maintained as an option.

There are two *IN* and *EV* record grouping options, by year and by control point. Grouping by control point requires more active computer memory in *SIM* than grouping by year but may be more convenient. With the option of grouping *IN* and *EV* records by year, *SIM* reads the *IN* and *EV* records for only one year in an iterative annual loop. With the option of grouping the *IN* and *EV* records by control point, all of the *IN* and *EV* records are read at the beginning of the simulation, requiring much more memory. In typical applications for large river basins, *SIM* simulations may involve numerous ungaged secondary control points that are not addressed in *HYD*. Thus, the reduction in computer memory requirements associated with grouping by year can be quite significant for *SIM*.

Grouping by Year			Grouping by Control Point		
IN	CP-1	2001	IN	CP-1	2001
IN	CP-2	2001	IN	CP-1	2002
IN	CP-3	2001	IN	CP-1	2003
IN	CP-1	2002	IN	CP-1	2004
IN	CP-2	2002	IN	CP-2	2001
IN	CP-3	2002	IN	CP-2	2002
IN	CP-1	2003	IN	CP-2	2003
IN	CP-2	2003	IN	CP-2	2004
IN	CP-3	2003	IN	CP-3	2001
IN	CP-1	2004	IN	CP-3	2002
IN	CP-2	2004	IN	CP-3	2003
IN	CP-3	2004	IN	CP-3	2004

## **Alternative Organizational Formats for Flows and Evaporation-Precipitation Depths**

The options for organizing input datasets of monthly stream flow volumes (gaged, naturalized, or otherwise) and reservoir surface evaporation-precipitation rates are specified by the parameters JC(1) and JC(2) in JC record fields 5 and 6. The options are as follows.

### **Option 1 for JC(1) and JC(2) on JC Record**

IN and EV records are stored in separate files, with filename extensions FLO and EVA, respectively. The records are in the standard default format shown on page 200. In the FLO and EVA files, the IN and EV records for all control points are grouped together by year. All of the records for a year are followed by a complete set of records for the next year.

With the option 1 grouping of IN and EV records by year, SIM reads the IN and EV records for only one year in an iterative annual loop requiring significantly less computer memory than option 2. The choice of option 1 versus option 2 does not affect HYD memory requirements since the FLOW(cp,year,month) and EP(cp,year,month) arrays are handled the same with either option.

### **Option 2 for JC(1) and JC(2) on JC Record**

Option 2 is identical to option 1 except the IN and EV records are grouped by control point. All records for all years for the first control are grouped together before the records for the second control point.

### **Option 3 for JC(1) and JC(2) on JC Record**

IN and EV records are stored in a single file with the filename extension root1.HYD. Pairs of records with six months on each are in the format shown on page 201. The records for all control points are grouped together a particular year. All the records for a year are followed by a complete set of records for the next year. The set of all IN records for all control points for a particular year is followed by the set of all EV records for that year.

### **Option 4 for JC(1) and JC(2) on JC Record**

Option 4 is identical to Option 3 except each record contains 12 stream flows or evaporation-precipitation depths rather than six.

### **Option 5 for JC(1) and JC(2) on JC Record**

The stream flow and evaporation data are tabulated in columns in FLO and EVA files.

### **Option 6 for JC(1) and JC(2) on JC Record**

The monthly river flow volumes and evaporation-precipitation depths are read from a binary Hydrologic Engineering Center Data Storage System file with filename extension DSS.

### **Option 7 for JC(1) and JC(2) on JC Record**

Flow volumes and evaporation-precipitation depths are read from a SIM output OUT file

## FD Record – Flow Distribution

field	columns	variable	format	value	description
1	1-2	CD	A2	FD	Record identifier
2	3-8	ID	A6	AN	Control point identifier for ungaged CP
3	11-16	DSG	2x,A6	AN	Source gaged control point
4	17-24	NG	I8	+ -1	Number of gaged cp's above ungaged site (blank = 0) Ungaged CP is downstream of source CP
5-no limit	25-no limit	UGID(I) I=1,MAXGAG	2x,A6	AN	Identifiers of upstream gaged control points No limit on the maximum number of identifiers.

## FC Record – Coefficients for Flow Distribution Equation

field	columns	Variable	format	value	description
1	1-2	CD	A2	FC	Record identifier
2	3-8	COEF1	F6.0	+	Coefficient $a$ (may be drainage area ratio)
3	9-16	COEF2	F8.0	+ or -	Coefficient $b$ (default = 1.0)
4	17-24	COEF3	F8.0	+ or -	Coefficient $c$ (default = 0.0) $Q_{\text{ungaged}} = a Q_{\text{gaged}}^b + c$

## WP Record – Watershed Parameters

field	columns	variable	format	value	description
1	1-2	CD	A2	WP	Record identifier
2	3-8	ID	A6	AN	Control point identifier
3	9-16	DA	F8.0	+	Drainage area
4	17-24	CN	F8.0	+	Curve number
5	25-32	MP	F8.0	+	Mean precipitation
6	33-40	DAF	F8.0	+	Multiplier to convert drainage area to square miles

*FD*, *FC*, and *WP* records are stored in a flow distribution file with filename root.DIS. The DIS file ends with an end-of-file *ED* record. The DIS file *FD*, *FC*, and *WP* records have the same format, organization, and content with either *HYD* or *SIM*. The explanatory notes provided with the *FD*, *FC*, and *WP* records in Chapter 3 of this *Users Manual* [2] are pertinent here as well. Chapter 3 of the *Reference Manual* [1] covers the alternative flow distribution methods for computed naturalized flows at ungaged control points based on flows at gaged control points.

A *FC* record must follow directly behind its *FD* record. Otherwise, the *FD/FC* and *WP* records may be in any order in the DIS file. The records are stored in a DIS file that ends with an *ED* record. The end-of-file *ED* record is required.

## AS Record – Stream Flow Adjustment Specifications

field	columns	variable	format	value	description
1	1-2	CD	A2	AS	Record identifier.
2	3-8	ID	A6	AN	Control point identifier.
<u>Beginning and Ending Years of Adjustments</u>					
3	13-16	AS(1)	I8	blank, 0 +	First year of adjustments = first year of analysis. First year of adjustments.
4	21-24	AS(2)	I8	blank, 0 +	Last year of adjustments = last year of analysis. Last year of adjustments.
<u>Source of Adjustments</u>					
5	28	AS(3)	I4	1	Following <i>FA</i> records.
				-1	Following <i>FA</i> records in format that includes the year and control point.
				2	Following <i>RS</i> and <i>SC</i> records.
				-2	Following <i>RS</i> and <i>SC</i> records with <i>SC</i> records in format that includes year and control point.
				3	<i>CI</i> records previously read from root1.DAT file.
				4	Constant adjustment from field 11 below.
				5	<i>SIM</i> OUT file data specified in field 6 below.
<u>Data from SIM Output OUT File</u>					
6	32	AS(4)	I4	blank, 0	No flow adjustment data from <i>SIM</i> output OUT file.
				1	Naturalized flows from control point output (NAT).
				2	Regulated flows from control point output (REG).
				3	Unappropriated flows from cp output (UNA).
				4	Stream flow depletions from cp output (DEP).
				5	Return flows from control point output (RFR).
				6	Diversions targets from control point output (TAR)
				7	Diversions at control point (DIV = TAR – SHT)
				8	Diversions shortage from control point output (SHT)
				9	Flow depletions from water right output (DEP).
				10	Return flows from water right output (RFL).
				-10	<i>HYD</i> shifts return flows (RFL) forward one month.
				11	Diversions for WR or releases for IF right (DIV).
				12	End-of-month reservoir storage volume (STO)
				13	Reservoir storage capacity (RSC)
14	Reservoir storage drawdown ( RSD = RSC – STO )				
<u>Negative Values for Flow Adjustments</u>					
7	36	AS(5)	I4	blank, 0	Apply adjustments regardless of sign (+ or -).
				1	Set negative adjustments equal to zero.
				2	Set positive adjustments equal to zero.
<u>Cascade Downstream? Yes or No?</u>					
8	40	AS(6)	I4	blank, 0	Adjustments apply to all downstream control points.
				1	Adjustments apply to only this control point.

Continued on next page.

## AS Record – Stream Flow Adjustment Specifications (Continued)

field	columns	variable	format	value	description
<u>Negative Flow Options</u>					
9	44	AS(7)	I4	blank, 0 1 2 3 4	Allow negative stream flows. Change negative stream flows to zero. Change to zero and subtract next month. Modify adjustments to prevent negative stream flows Modify adjustments and subtract negative next month
<u>Multiplier Factor</u>					
10	45-52	AS8	F8.0	+	Factor to multiply flow adjustments (default=1.0).
<u>Constant Flow Adjustment</u>					
11	53-60	AS9	F8.0	+	Constant flow adjustment applied in all months.
<u>CP or WR Identifier for Field 6 Data from OUT File</u>					
12	61-68	AS10	2x,A6	blank AN	Data at field 2 control point is used for adjustment. Control point identifier for field 6 data.
13	69-84	AS11	A16	blank AN	Options 6, 7, or -7 are not selected in field 6. Water right identifier for field 6 data.

Any number of sets of AS records and accompanying FA, RS, and SC records can be used to specify adjustments to the monthly stream flow volumes in the FLOW(cp,year,month) array. Adjustments are volumes to be added to the flow volumes currently stored in the FLOW array. Each AS record defines a particular set of monthly flow adjustments to be added to flows at a selected control point and optionally at control points located downstream of that control point. The flow volume adjustments may be either positive or negative amounts. The different types of stream flow adjustments are outlined in Chapter 3 of the *Reference Manual* [1].

### Explanation of AS Record Fields

**Field 2:** The identifier of the control point at which the adjustments are introduced is entered in field 2. Depending on AS(6) in field 8, the adjustments may be limited to only flows at this control point or alternatively may be cascaded downstream affecting flows at downstream control points as well.

**Fields 3 and 4:** AS(1) and AS(2) define the period of years for which the flow adjustments are applied. The default is to cover the period-of-analysis defined by JC record fields 2 and 3. However, AS(1) and AS(2) can be used to define a sub-period consisting of an integer number of years falling within the overall period-of-analysis defined in JC record fields 2 and 3.

**Field 5:** The parameter AS(3) specifies the type of flow adjustment and data source. The following alternative adjustments to the monthly flow volumes in the FLOW(cp,year,month) array may be selected for application with this particular AS record.

1. The monthly stream flow volumes may be adjusted by adding amounts read from a set of flow adjustment FA records that follow immediately behind the AS record.

2. Adjustments for reservoirs may be computed based on information provided by *RS* and *SC* records that follow after the *AS* record. The computed reservoir adjustments are added to the flows in the *FLOW* array just like any other type of adjustment.
3. A set of 12 adjustments read from a *CI* record for this control point may be added each year to the flows for the 12 months of the year. *CI* records are stored in the *HIN* file following the *CP* records.
4. A constant adjustment *AS9* entered in *AS* record field 11 may be added to all flows.
5. The adjustments to be added to the flows in the *FLOW*(cp,year,month) array may be the variable defined by *AS*(4) read from the *SIM* simulation output *OUT* file.

For options 1, -1, 2, and -2, the format of the *FA* and *SC* records vary depending on *AS*(3) in *AS* record field 5. The only difference in the alternative format of the *FA* and *SC* records is whether or not fields for the control point identifier and year are included. With options -1 and -2, the control point identifier and year are included on the *FA* and *SC* records. With options 1 and 2, these fields are omitted.

**Field 6:** *AS*(4) in field 6 is relevant only if option 5 is selected for *AS*(3) in field 5. *AS*(4) selects the variable from the array of variables read from the *OUT* file to use for the adjustments.

**Field 7:** The adjustments defined by the parameters in fields 5 and 6 above may be either positive or negative amounts. With *AS*(5) of zero (blank field 7), the default is to add the adjustment amount to the flow in the *FLOW* array regardless of whether a negative or positive number is being added. With a 1 for the *AS*(5) switch, negative adjustment amounts are set equal to zero. With *AS*(5) option 2, positive adjustments are set equal to zero.

**Field 8:** The adjustment amounts are added to the flows in the *FLOW*(cp,year,month) array at the control point specified as *ID* in *AS* record field 2. If a 1 is entered for switch *AS*(6) in field 8, only the flows at that control point are adjusted. However, the default (zero or blank field 8) is to also cascade the adjustments to all control points located downstream of the control point defined in field 2. Channel losses defined by channel loss factors from the *CP* records are incorporated in the translation of the adjustments to downstream control points. The identifiers of next downstream control points on the *CP* records also define the spatial connectivity of the river system required to cascade to adjustments downstream.

**Field 9:** The results of adding adjustment amounts, which may be either positive or negative, to the flow volumes in the *FLOW*(cp,year,month) array may result in negative flow volumes in some months. Stream flow volumes normally should not be negative. *AS*(7) provides the following options for dealing with negative stream flows.

1. Negative flows may be allowed.
2. Negative flow values may be replaced with zeros with no further action.
3. Negative flow values may be replaced with zeros and the amount of the negative amount remaining subtracted from the flow in the next month. If that results in a negative flow in the next month, that flow is set to zero with the negative amount again forwarded to the following month.

4. The adjustment may be modified as necessary to prevent the control point flow in the FLOW array from being negative. The modified adjustment is incorporated in the cascading computations meaning a different adjustment is now being added to flows at downstream control points.
5. Option 4 is the same as option 3 except the remaining negative amount of the adjustment associated with setting the adjustment equal to zero is subtracted from the next month flow similarly as option 2.

Negative flow options AS(7) in AS record field 9 may be applied with each individual AS record set of adjustments. Alternatively, the negative flow options may be applied to the final stream flows after all cumulative adjustments by inserting a final AS record with AS(3) of 4 in field 5 and AS9 of 0.0 in field 11.

**Field 10:** AS8 is an optional factor by which the flow adjustments are multiplied prior to being added to the FLOW array flows. AS8 can be a unit conversion factor or serve other purposes.

**Field 11:** AS9 is a constant adjustment amount that is added to the FLOW(cp,year,month) flow volumes in all months if AS(3) option 4 is specified in field 5.

**Fields 12 and 13:** Fields 12 and 13 are relevant only if AS(3) option 5 is specified in field 5 indicating that adjustments are amounts read from a *SIM* simulation results OUT file. The variables defined by field 5 AS(4) options 1, 2, 3, 4, and 5 are associated with control points. The variables defined by AS(4) options 6, 7, and 8 are associated with water rights.

AS10 in AS record field 12 is a control point identifier specifying the control point for which data from the OUT file are adopted as adjustments for AS record field 5 AS(4) options 1, 2, 3, 4, and 5. The default (blank field 12) is the control point identifier ID entered in field 2.

AS11 in AS record field 13 is a water right identifier specifying the water right for which data from the OUT file are adopted as adjustments for AS record AS(4) options 6, 7, -7, and 8. There is no default. If AS(4) option 6, 7, -7, or 8 is selected in field 6, a water right identifier must be specified for AS11 in field 13. This water right identifier must be found in the *SIM* OUT file.

### **Sequencing of AS, FA, RS, SC and EQ Records in HIN or FLO Files**

The set of all *EQ*, *AS*, *FA*, *RS*, and *SC* records may be placed as the last records in either the HIN and/or FLO files as specified by *JC*(3) entered in field 7 of the *JC* record. The *ED* record is always the last record in HIN file. An *ED* record is also placed at the end of a FLO file if the FLO file contains *EQ*, *AS*, *FA*, *RS*, or *SC* records. Thus, the set of all *EQ*, *AS*, *FA*, *RS*, and *SC* records are always immediately followed by an end-of-data *ED* record ending a HIN or FLO file.

- An AS record precedes each set of FA records and each set of RS/SC records.
- All FA records for a particular control point are grouped together as a set following their AS record.
- A RS record precedes each group of SC records and is preceded by an AS record.
- SC records for a control point are grouped together following their AS/RS records.
- EQ records may be before, after, or between sets of AS/FA and AS/RS/SC records.

## FA Record – Stream Flow Adjustments

field	columns	variable	format	value	description
1	1-2	CD	A2	FA	Record identifier (optional after first record)
2	3-8	FA(1)	F6.0	+	Stream flow adjustment for month 1
3	9-16	FA(2)	F8.0	+	Stream flow adjustment for month 2
4	17-24	FA(3)	F8.0	+	Stream flow adjustment for month 3
5	25-32	FA(4)	F8.0	+	Stream flow adjustment for month 4
6	33-40	FA(5)	F8.0	+	Stream flow adjustment for month 5
7	41-48	FA(6)	F8.0	+	Stream flow adjustment for month 6
8	49-56	FA(7)	F8.0	+	Stream flow adjustment for month 7
9	57-64	FA(8)	F8.0	+	Stream flow adjustment for month 8
10	65-72	FA(9)	F8.0	+	Stream flow adjustment for month 9
11	73-80	FA(10)	F8.0	+	Stream flow adjustment for month 10
12	81-88	FA(11)	F8.0	+	Stream flow adjustment for month 11
13	89-96	FA(12)	F8.0	+	Stream flow adjustment for month 12

## FA Record – Stream Flow Adjustments (Alternative format with control point ID and year)

field	columns	variable	format	value	description
1	1-2	CD	A2	FA	Record identifier (optional)
2	3-8	ID	A6	AN	Control point identifier (optional)
3	13-16	PYR	I8	+	Year (optional)
4	17-24	FA(1)	F8.0	+	Stream flow adjustment for month 1
5	25-32	FA(2)	F8.0	+	Stream flow adjustment for month 2
6	33-40	FA(3)	F8.0	+	Stream flow adjustment for month 3
7	41-48	FA(4)	F8.0	+	Stream flow adjustment for month 4
8	49-56	FA(5)	F8.0	+	Stream flow adjustment for month 5
9	57-64	FA(6)	F8.0	+	Stream flow adjustment for month 6
10	65-72	FA(7)	F8.0	+	Stream flow adjustment for month 7
11	73-80	FA(8)	F8.0	+	Stream flow adjustment for month 8
12	81-88	FA(9)	F8.0	+	Stream flow adjustment for month 9
13	89-96	FA(10)	F8.0	+	Stream flow adjustment for month 10
14	97-104	FA(11)	F8.0	+	Stream flow adjustment for month 11
15	105-112	FA(12)	F8.0	+	Stream flow adjustment for month 12

A set of *FA* records is preceded an *AS* record with *AS*(3) option 1 or –1 specified in *AS* record field 5. The choice of format for both the *FA* and *SC* records is specified by *AS*(3) in field 5 of the *AS* record. The only difference between the two format options is whether to include optional fields for the control point ID and year *PYR* as fields 2 and 3. These records, like all others, may also be in comma delimited format.

## RS Record – Reservoir Specifications for Stream Flow Adjustments

field	columns	variable	format	value	description
1	1-2	CD	A2	RS	Record identifier
2	3-8	ID	A6	AN	Reservoir identifier
<i>Adjustment Components</i>					
3	16	RS(1)	I8	blank,0 1 -1 -9	Add storage increase (default) Add storage increase Subtract storage increase Do not consider storage increase
4	24	RS(2)	I8	blank,0 1 -1 -9	Subtract conservation storage decrease (default) Add conservation storage decrease Subtract conservation storage decrease Do not consider conservation storage decrease
5	32	RS(3)	I8	blank,0 1 -1 -9	Subtract flood storage decrease (spill) (default) Add flood storage decrease (spill) Subtract flood storage decrease (spill) Do not consider flood storage decrease (spill)
6	48	RS(4)	I8	blank,0 1 -1 -9	Add net evaporation-precipitation (default) Add net evaporation-precipitation Subtract net evaporation-precipitation Do not consider net evaporation-precipitation
7	48	RS(5)	I8	blank,0 1 -1 -9	Add watershed runoff from reservoir site (default) Add watershed runoff from reservoir site Subtract watershed runoff from reservoir site Do not consider runoff from reservoir site
<i>Reservoir Adjustments Table</i>					
8	56	RS(6)	I8	blank,0 1	Option not used Adjustments table written to HOT file
<i>Reservoir Information</i>					
9	57-64	CAP	F8.0	+	Reservoir storage capacity
10	65-72	EVCFA	F8.0	+	Multiplier <i>A</i> for storage-area equation shown below.
11	73-80	EVCFB	F8.0	+	Exponent <i>B</i> for storage-area equation shown below.
12	81-88	EVCFC	F8.0	+	Constant <i>C</i> for storage-area equation shown below. $\text{surface area} = A (\text{storage})^B + C$
13	88-96	RS7	F8.0	+	Beginning storage (beginning of first month)
				blank,0	Beginning storage content is zero
14	97-104	RS8	F8.0	+	Factor to multiply storage contents
				blank, 0	Default RS7 = 1.0

The RS record controls computation of adjustment amounts reflecting the impacts of reservoir storage to be added to the FLOW(cp,year,month) array flows in accordance with specifications on the preceding AS record. The component reservoir adjustments are outlined in Chapter 3 of the *Reference Manual*. A RS record is preceded by an AS record and followed by SC records.

## SC Record – Storage Contents

field	columns	variable	format	value	description
1	1-2	CD	A2	SC	Record identifier (optional)
2	3-8	SC(1)	F6.0	+	Storage contents for month 1
3	9-16	SC(2)	F8.0	+	Storage contents for month 2
4	17-24	SC(3)	F8.0	+	Storage contents for month 3
5	25-32	SC(4)	F8.0	+	Storage contents for month 4
6	33-40	SC(5)	F8.0	+	Storage contents for month 5
7	41-48	SC(6)	F8.0	+	Storage contents for month 6
8	49-56	SC(7)	F8.0	+	Storage contents for month 7
9	57-64	SC(8)	F8.0	+	Storage contents for month 8
10	65-72	SC(9)	F8.0	+	Storage contents for month 9
11	73-80	SC(10)	F8.0	+	Storage contents for month 10
12	81-88	SC(11)	F8.0	+	Storage contents for month 11
13	89-96	SC(12)	F8.0	+	Storage contents for month 12

## SC Record – Storage Contents (Alternative format with control point ID and year PYR)

field	columns	variable	format	value	description
1	1-2	CD	A2	SC	Record identifier (optional after first record)
2	3-8	ID	A6	AN	Reservoir (optional)
3	13-16	PYR	I8	+	Year (optional)
4	17-24	SC(1)	F8.0	+	Storage contents for month 1
5	25-32	SC(2)	F8.0	+	Storage contents for month 2
6	33-40	SC(3)	F8.0	+	Storage contents for month 3
7	41-48	SC(4)	F8.0	+	Storage contents for month 4
8	49-56	SC(5)	F8.0	+	Storage contents for month 5
9	57-64	SC(6)	F8.0	+	Storage contents for month 6
10	65-72	SC(7)	F8.0	+	Storage contents for month 7
11	73-80	SC(8)	F8.0	+	Storage contents for month 8
12	81-88	SC(9)	F8.0	+	Storage contents for month 9
13	89-96	SC(10)	F8.0	+	Storage contents for month 10
14	97-104	SC(11)	F8.0	+	Storage contents for month 11
15	105-112	SC(12)	F8.0	+	Storage contents for month 12

SC records contain end-of-month reservoir storage volumes used in conjunction with RS record computations. The choice of format for both the FA and SC records is specified by AS(3) in field 3 of the AS record. The only difference between the two options is whether to include optional fields for the control point ID and year PYR as fields 2 and 3. With the AS(3) option 2, the ID and PYR fields are omitted. With the AS(3) option -2, the ID and PYR fields are included. These records, like all others, may also be in comma delimited format.

Each set of SC records in the HIN or FLO file is preceded by a RS record. The RS record is preceded by an AS record. Each set of RS/SC records is associated with a specified control point.

## EQ Record – Adjustment Equation

field	columns	variable	format	value	description	
1	1-2	CD	A2	AS	Record identifier	
2	3-8	ID	A6	AN	Control point identifier of Q or E.	
<u>Type of Adjustments</u>						
3	16	QE	I8	blank,0,1	Flow	$Q_{\text{adjusted}} = A Q^B + C$
					Flow Change	$\Delta Q_{\text{adjustment}} = (A Q^B + C) - Q$
					Evap-Precip	$E_{\text{adjusted}} = A E^B + C$
<u>Equation Coefficients</u>						
4	17-24	A	F8.0	+	Coefficient A	(Default = 0.0)
5	25-32	B	F8.0	+	Coefficient B	(Default = 1.0)
6	37-40	C	F8.0	+	Coefficient C	(Default = 0.0)
<u>Range of Q or E Values to Adjust</u>						
7	41-48	MINQ	F8.0	+	Minimum Q or E for which adjustment is applied.	
8	49-56	MAXQ	F8.0	+	Maximum Q or E for which adjustment is applied.	
<u>Beginning and Ending Years of Adjustments</u>						
9	61-64	AEQ(1)	I8	blank,0	First year adjustments = first year of analysis period	
					+	First year of adjustments
10	69-72	AEQ(2)	I8	blank,0	Last year adjustments = Last year of analysis period	
					+	Last year of adjustments
<u>Cascade Downstream</u>						
11	76	AEQ(6)	I4	0	QE=2 adjustments apply to all downstream cp's.	
				1	QE=2 adjustments apply to only this control point.	
<u>Negative Flow Options</u>						
12	80	AEQ(7)	I4	0	Allow negative stream flows.	
				1	Change negative stream flows to zero.	
				2	Change to zero and subtract next month.	
				3	Modify adjustments to prevent negative stream flows.	
				4	Modify adjustments and subtract negative next month	
<u>Control Point of the Adjusted Flow or Evap-Precip</u>						
13	81-88	ID2	2x,A6	blank	ID2 defaults to ID entered in field 2.	
				AN	Control point identifier of $Q_{\text{adjusted}}$ or $E_{\text{adjusted}}$	

EQ records are grouped with AS/FA/RS/SC records and may be placed before, after, or interspersed with the AS/FA/RS/SC records. These records are the last records in either the HIN and/or FLO files as specified by JC(3) entered in JC record field 7.

The EQ record computes monthly stream flow volumes ( $Q_{\text{adjusted}}$ ) as a function of the stream flow volumes (Q) in the FLOW array or monthly evaporation-precipitation depths ( $E_{\text{adjusted}}$ ) as a function evaporation-precipitation depths (E) in the EP array based on the following equations (QE options 1 or 3).

$$Q_{\text{adjusted}} = A Q^B + C \quad \text{or} \quad E_{\text{adjusted}} = A E^B + C$$

The coefficients A, B, and C are provided as input in *EQ* record fields 4, 5, and 6. Alternatively, stream flow adjustments  $\Delta Q_{\text{adjustment}}$  can be computed with the following equation (QE option 2). Adjustments thus computed are handled identically to the adjustments associated with *FA* or *RS* records.

$$\Delta Q_{\text{adjustment}} = (A Q^B + C) - Q$$

### **Explanation of EQ Record Fields**

ID, AEQ(1), AEQ(2), AEQ(6), and AEQ(7) in fields 2, 9, 10, 11, and 12 of the *EQ* record are identical to ID, AS(1), AS(2), AS(6), and AS(7) in fields 2, 3, 4, 8, and 9 of the *AS* record.

**Field 2:** The identifier of the control point at which the adjustment equations are applied. Depending on QE in field 3 and AS(6) in field 11, the adjustments may be limited to only flows at this control point or alternatively may be cascaded downstream affecting flows at downstream control points as well.

**Field 3:** Parameter QE in field 3 specifies whether flow volumes (Q) or evaporation-precipitation depths are being adjusted. The QE selection also includes two options for adjusting flows. Stream flows volumes (QE=1) or evaporation-precipitation depths (QE=3) are adjusted by direct substitution into the equation.

$$Q_{\text{adjusted}} = A Q^B + C \quad \text{or} \quad E_{\text{adjusted}} = A E^B + C$$

Alternatively, for stream flows (QE=2), a change in flow  $\Delta Q_{\text{adjustment}}$  may be computed that is then handled identically as adjustments read from *FA* records or computed in accordance with *RS* records.

$$\Delta Q_{\text{adjustment}} = (A Q^B + C) - Q$$

Only  $\Delta Q_{\text{adjustment}}$  may be applied to downstream control points. Therefore, AS(6) in *EQ* record field 11 is not used unless option 2 is selected for QE in field 3.

**Fields 4, 5, 6:** The coefficients A, B, and C in the adjustment equations are entered as input.

**Fields 7, 8:** With QE options 1 or 3 specified in field 3, the range of values to which the flow adjustment equation is applied can optionally be limited to the range defined by the minimum and maximum values for Q or E entered in fields 7 and 8. The adjustment equation is applied only in months in which the Q or E equals and exceeds MINQ (field 7) and does not exceed MAXQ (field 8). The default is to apply the adjustment equation for all values of Q or E.

**Fields 9 and 10:** AEQ(1) and AEQ(2) define the period of years for which the flow adjustments are applied. The default is to cover the period-of-analysis defined by *JC* record fields 2 and 3. However, AEQ(1) and AEQ(2) can be used to define a sub-period consisting of an integer number of years falling within the overall period-of-analysis defined in *JC* record fields 2 and 3.

**Field 11:** AEQ(6) in *EQ* record field 11 is relevant only if option 2 is selected for QE in *EQ* record field 3. The adjustment quantities are added to the flows in the *FLOW* array at the control point specified as ID in *EQ* record field 2. If a 1 is entered for switch AEQ(6) in field 11, only the flows at that control point are adjusted. However, the default (zero or blank field 11) is to

also cascade the adjustments to all control points located downstream of the control point defined in field 2. Channel losses defined by channel loss factors from the *CP* records are incorporated in the translation of the adjustments to downstream control points.

**Field 12:** negative flow options are identical in *AS* record field 9 and *EQ* record field 12. AEQ(7) in *EQ* record field 12 is relevant only if option 2 is selected for QE in *EQ* record field 3.

**Field 13:** ID2 entered in field 13 is the identifier of the control point for which adjusted flows ( $Q_{\text{adjusted}}$ ) are evaporation-precipitation rates ( $E_{\text{adjusted}}$ ) are computed and recorded in the *FLOW* array or *EP* array for QE options 1 and 3. ID in field 2 is the identifier of the control point for flows (Q) or evaporation-precipitation rates (E) are read from the *FLOW* array or *EP* array. The default is to assign IN to ID2. A non-blank field 13 allows flows, evaporation-precipitation rates, or other variables for a particular control point to be computed as a function of quantities at another control point. The default is to adjust the quantities for the control point with identifier ID entered in field 2 and assign the adjusted flows to this same control point for which ID is entered in field 2.

## CHAPTER 8

### INPUT RECORDS FOR HYD FEATURES DESCRIBED IN CHAPTERS 5 AND 6

The preceding Chapter 7 covers input records for the *HYD* features presented in Chapters 3 and 4. Chapter 8 describes the additional input records required for the features presented in Chapters 5 and 6 for extending hydrologic periods-of-analysis.

*HYD* input files are listed in Table 1.1. The *FE* record requires HIN, FLO, and the Precipitation.PPP and Evaporation.EEE input files. The *EE* record requires HIN, EVA, and Evaporation.EEE input files. The results recorded in HMS, HOT, FLO, EVA, and/or DSS files are controlled by *JC* record input parameters JC(8) and JC(9) as well as *FE* and *EE* records.

The *HYD* input HIN file always begins with a job control *JC* record and ends with an end of data *ED* record described in Chapter 7. Optional comment *\*\** records may be inserted throughout the HIN file. The *JC* and *ED* records are required to apply any of the *HYD* capabilities including the capabilities controlled with the *FE*, *FP*, and *EE* records presented in this chapter. Other existing general-use input records described in Chapter 7, primarily the *CP*, *IN*, and *EV* records, are also used with the *FE*, *FP*, and *EE* records covered in Chapter 8.

As previously discussed, *HYD* consists of a set of routines for creating, adjusting, and writing data arrays. Most *HYD* operations, including those addressed here, work with the arrays *FLOW(control point, year, month)* and *EP(control point, year, month)*. The *FLOW* array contains monthly stream flow volumes (acre-feet/month). The *EP* array contains monthly evaporation rates, precipitation rates, or net evaporation-precipitation rates (depth/month or volume/month). The *FLOW* and *EP* arrays are initially populated from the FLO and EVA input files subject to adjustments and extensions resulting from the program *HYD* computations.

In applying the *FE/FP* record parameter calibration, known flows from the TCEQ WAM System dataset are stored in the *FLOW(cp,yr,month)* array. The *FE* record flow extension and *EE* record net evaporation-precipitation extension routines extend the *FLOW* and *EP* arrays.

- With the *FE/FP* record parameter calibration, the *FLOW(cp,yr,month)* array covers the years of flow in the original WAM System hydrologic period-of-analysis.
- With the *FE* record flow extension, the *FLOW(cp,yr,month)* and *EP(cp,yr,month)* arrays cover both the extension period and the original period-of-analysis.
- With the *EE* record evaporation-precipitation extension, the *EP(cp,yr,month)* array covers the extension period and may also include the original period-of-analysis.

All elements of the *FLOW(cp,yr,month)* and *EP(cp,yr,month)* arrays are set equal to zero at the beginning of a *HYD* execution. Initially, the arrays are partially or completely filled with data read by *HYD* from input files in accordance with specifications on the *JC* record. *JC* record parameters also specify the format and organization of the output files to which the arrays are written at the end of the *HYD* execution. *CP* records are required in the HIN file for all control points included in the relevant FLO and EVA input files. The record identifier and control point identifier in the first two fields are the only information required on the *CP* records for *FE* and *EE* record applications, though the other *CP* record fields can also be used if and as needed.

## **Input Records for the Hydrologic Period-of-Analysis Extension Procedures**

The records listed below are placed in the main *HYD* input HIN file.

- EE Record – compilation of sequences of evaporation-precipitation rates
- EX Record – monthly precipitation multiplier factors for *EE* record computations
- QD Record – quadrangle identifiers
- QA Record – areas of quadrangles within watershed (*FE*) or reservoir (*EE record*)
- FE Record – flow extension computations including both calibration and extension
- FN Record – names used to label output
- FP Record – calibration of parameters for the flow model
- BM Record – monthly seasonal base flows in the flow model
- B1, B2, B3, B4 Records – base flows for flow, medium, high, and flood flow conditions
- XP Record – rainfall-runoff coefficients in the flow model
- X1, X2, X3, X4 Records – coefficients for low, medium, high, and flood flow conditions
- FZ Record – flow limits defining flow zones
- FR Record – flow limits defining flow ranges
- UB Record – flow extension parameters  $ZF(k)$ ,  $U(z,k)$ , and  $BX(z)$
- FX Record – multiplier factors  $FX(r)$  for final flow adjustments
- RC Record – regression coefficients relating computed and known flows

Routines activated by the *FE*, *FP*, and *EE* records and auxiliary records listed above were added to *HYD* to provide capabilities for extending hydrologic periods-of-analysis using precipitation and evaporation datasets available from the Texas Water Development Board.

- The *FE* and *FP* records develop parameters for the flow equation based on naturalized flows from a WAM dataset and precipitation and evaporation depths from the TWDB datasets covering the original hydrologic period-of-analysis. The *FE* record also applies the flow equation with precipitation and evaporation depths from the TWDB dataset covering the period of the extension to synthesize flows. The *FP* record is a continuation of the *FE* record with additional input data entries.
- The *EE* record extends an EVA file of net reservoir surface evaporation-precipitation depths using precipitation and evaporation depths from the TWDB dataset. Other uses of the evaporation and precipitation datasets are also facilitated. The *EX* record provides supplemental data used with a particular option on the *EE* record.
- *QD* and *QA* are used with both the *EE* record extension of net evaporation-precipitation depths and the *FE* record extension of naturalized stream flows.
- *BM*, *B1*, *B2*, *B3*, *B4*, *XP*, *X1*, *X2*, *X3*, *X4*, *FZ*, *ZR*, *UB*, *FX*, and *RC* records created by *HYD* provide data for flow extension operations controlled by the *FE* record.

*QD* and *QA* records are required with an *EE* record when working with more than one quadrangle but are not required when using a single quadrangle. The other records are not relevant with an *EE* record. A pair of *QD* and *QA* records is required following the *FE* record. *FP*, *FZ*, and *FR* records also follow after a *FE* record. The other records are created by *HYD* during the calibration process. These records with calibration results are included in the set of auxiliary records that follow the *FE* record controlling the flow extension.

## EE Record – Evaporation-Precipitation Extension

field	columns	variable	format	value	description
1	1-2	CD	A2	EE	Record identifier
2	3-8	ID	A6	AN	Control point identifier
3	9-16	QD1	I8	+	Quadrangle identifier if only one quadrangle is used
4	17-24	YRBEGEX	I8	+	Beginning year of extension
5	25-32	YRENDEX	I8	+	Ending year of extension
6	32-36	EEMSS	I4	1 2 3	Summary statistics are recorded in HMS file. <i>EV</i> records and summary statistics in HMS file. Summary statistics in HOT file if JC(9)=7.
7	37-40	EE	I4	blank,0 1 2 3 4 5 6 7	EE for preceding control point is repeated. Evaporation – precipitation depths in inches Evaporation depths in inches Precipitation depths in inches Evaporation – precipitation volumes in ac-ft/month Evaporation depths in acre-feet/month Precipitation depths in acre-feet/month Evaporation – XEX(m)×precipitation depth in inches
8	41-48	EEX	F8.0	F8.0	Multiplier factor such as unit conversion factor
9	49-56	EDSS	A16	AN	First part of DSS pathname. Default is filename.

## EX Record – Monthly Precipitation Multiplier Factors for EE Option 7 Added Only for Option 7

field	columns	variable	format	value	description
1	1-2	CD	A2	EX	Record identifier
2	3-8	XEX(1)	F6.0	+	Precipitation multiplier factor for first month
3	33-40	XEX(m) m=2,12	11F8.0	+	Multiplier factors for 2nd through 12th months

The *EE* record reads precipitation and evaporation depths in inches from the Precipitation.PPP and Evaporation.EEE files. Weighted averages for multiple quadrangles are computed. The precipitation and evaporation depths are combined as specified by EE in *EE* record field 6 with the results stored in the array EP(cp,yr,m). *JC* record field 13 controls the optional formats in which the EP(cp,yr,m) array is recorded in output files. The control point is specified in *EE* record field 2. The quadrangle identifier is entered in *EE* record field 3 if EE options 1, 2, 3, or 7 operations are applied to evaporation and/or precipitation depths for a single quadrangle. A pair of *QD* and *QA* records are required if data from more than one quadrangle are averaged.

*EE* record field 7 EE option 1 subtracts precipitation depths from evaporation depths to obtain net evaporation-precipitation depths. With EE option 7, the precipitation depths are multiplied by a factor XEX(m) from the *EX* record, and the resulting product is subtracted from the evaporation depth. Option 7 is designed for reservoir site precipitation runoff adjustments. EE options 2 and 3 simply write the evaporation or precipitation depths to files as specified by *JC* record field 13 and EEHMS in *EE* record field 5. The TWDB datasets are in units of inches. A

conversion factor of 0.083333 can be entered for the *EE* record field 8 EEX to convert inches to feet. *EE* options 4, 5, and 6 compute volumes in acre-feet based on land areas from *QA* records. For *EE* options 1, 2, 3, and 7, the *QD* and *QA* records serve the purpose of providing weighting factors for used in computing weighted averages. With *QA* record field 2 AA option 3, the numbers on the *QA* record are summed, and each number is divided by the summed total. Each quadrangle is thus assigned a fraction between 0.0 and 1.0 which total to 1.0. These fractions are multiplier factors used to compute weighted averages of the precipitation and evaporation data. For *EE* options 4, 5, and 6, the *QD* and *QA* records (AA options 1 and 2) provide areas in square miles that are applied to convert depths in inches to volumes in acre-feet.

### **QD Record – Quadrangle Identifiers**

field	columns	variable	format	value	description
1	1-2	CD	A2	QD	Record identifier
2	3-5	ND	I3	+	Number of quadrangles for DI and FE(11) option 2. blank,0 Default for ND is N.
3	6-8	N	I3	+	Total number of quadrangles
4	9-16	QD(1)	I6	+	Quadrangle identifier for 1st quadrangle
5	17-24	QD(2)	I8	+	Quadrangle identifier for 2nd quadrangle
6	25-32	QD(3)	I8	+	Quadrangle identifier for 3rd quadrangle
N+3		QD(N)	I8	+	Quadrangle identifier for Nth quadrangle

One pair of *QD* and *QA* records is required for each control point. With multiple *FE* records for the same control point, the *QD* and *QA* records are included with the first control point.

N in *QD* record field 3 denotes the number of quadrangles listed on the *QD* record. If *QD* record field 2 is blank or zero, ND defaults to N. The first ND quadrangles listed comprise a subset of the N quadrangles. The parameter ND is used for two different unrelated purposes in the *HYD* computations. Firstly, the ND quadrangles are used for the drought index. Secondly, ND is used with the enumeration optimization for FP record field 21 FE(11) option 2. There are ND enumerations FE(11) option 2. The first ND less one quadrangles are each enumerated separately. The NDth enumeration combines all remaining quadrangles.

The *QD* record lists the N quadrangles used with an *EE* record the *FE* records at a control point. For more than 12 quadrangles, 12 quads are listed on the first *QD* record and those after the 12th are listed on a second *QD* record. The identifiers are the three or four digit integer identifiers assigned by the TWDB and included in the Precipitation.PPP and Evaporation.EEE files.

The *QD* record is always required for a set of *FE* records and is also required following a *EE* record if more than one quadrangle is used. The *QA* record is optional. However, without a *QA* record, the *FE* record routine assumes that the entire area of each quadrangle is contained in the watershed. Without a *QA* record, the *EE* record weights the quadrangles the same in determining net evaporation-precipitation depths. A second *QA* record is used with more than 12 quadrangles.

## QA Record – Quadrangle Areas Located within Watershed

field	columns	variable	format	value	description
1	1-2	CD	A2	QA	Record identifier
2	3-8	AA	I6	blank,0,1	Areas in square miles are entered. 2 Fractions of quadrangle areas are entered. 3 Factors for weighted average that sum to 1.0.
3	9-16	QA(1)	F6.0	+	Area, fraction, or weighing factor (default=A or 1.0)
4	17-24	QA(2)	F8.0	+	Area, fraction, or weighing factor (default=A or 1.0)
5	25-32	QA(3)	F8.0	+	Area, fraction, or weighing factor (default=A or 1.0)
N+2		QA(N)	F8.0	+	Area or area fraction (default=A or 1.0)

The *QA* record follows a *QD* record and refers to the quadrangles on the *QD* record.

The QA(N) entered on the *QA* record are defined by AA in *QA* field 2. When used with a *FE* record, QA(N) for the N quadrangles may be either the area in square miles of the portion of the quad contained in the watershed (AA option 1) or fractional portion of the quadrangle area that is contained in the watershed (AA option 2). AA options 1 and 2 may also be used with *EE* options 4, 5, and 6 to provide areas in square miles to convert depths in inches to volumes in acre-feet.

*QA* record AA option 3 is designed for use with the *EE* record to provide weighting factors for use in computing weighted averages. The quantities on the *QA* record are summed, and each quantity is divided by the total to assign each quadrangle a fraction between 0.0 and 1.0 which sum to 1.0. These fractions are multiplier factors used to compute weighted averages of the precipitation and evaporation data used for developing *EV* records for an *EVA* file.

### **FE, FP, FZ, FR, BM, B1, B2, B3, B4, XP, X1, X2, X3, X4, UB, FX, and RC Records**

A set of *FP*, *FZ*, *FR*, *BM*, *B1*, *B2*, *B3*, *B4*, *XP*, *X1*, *X2*, *X3*, *X4*, *UB*, *FX*, and/or *RC* records follow each *FE* record in the HIN file to support the calibration and flow extension processes controlled by the *FE* records.

*HYD* is applied in calibration mode if FE(2) in *FE* record field 8 is non-zero. With *FE* record field 8 blank (FE(2)=0), *HYD* is applied in extension mode without performing calibration computations. With FE(2) of zero, values for the parameters are provided on input records.

*HYD* is executed in calibration mode (non-zero FE(2)) for the level 1 calibration. The *FP* record is used only for level 1 calibration. Normally, the *BM*, *B1*, *B2*, *B3*, *B4*, *XP*, *X1*, *X2*, *X3*, and *X4* records are automatically created by *HYD* during the level 1 calibration.

In flow extension mode (FE(2)=0), values of the parameters are provided in the HIN file on a set of *UB*, *BM*, *B1*, *B2*, *B3*, *B4*, *XP*, *X1*, *X2*, *X3*, *X4*, *FX*, and/or *RC* records. *HYD* is executed in flow extension mode (FE(2)=0) during level 2 calibration as well as for the final flow extension. *FX* records are created automatically by *HYD* during the level 2 calibration process. The parameters in *UB* record fields 4-14 are determined during the level 1 calibration process. The parameters in *UB* record fields 1 and 2 are added during level 2 calibration.

## FE Record – Flow Extension

field	columns	variable	format	value	description
1	1-2	CD	A2	FE	Record identifier
2	3-8	ID	A6	AN	Control point identifier
<i>Time Periods</i>					
3	9-14	YRBEGEX	I6	+	First year of extension period. Activates extension.
				blank,0,-1	Parameters are determined without extending flows.
4	15-20	YRENDEX	I6	+	Last year of extension period. Activates extension.
				blank,0,-1	Parameters are determined without extending flows.
5	21-26	YRBEG	I6	+	First year of analysis used to calibrate parameters.
				blank,0,-1	Default YRBEG is YRST from JC record.
6	27-32	YREND	I6	+	Last year of analysis used to calibrate parameters.
				blank,0,-1	Default YREND = YRST + NYRS – 1
<i>Information Recorded in HMS and HOT Files</i>					
7	33-36	FE(1)	I4	blank,0	Normal tracking messages to HMS file. No HOT file.
				1	Calibration results recorded in HMS and HOT files.
				2	Summary tables in HMS file without known flows.
				3	FX records added to calibration results in HOT file.
				4	Summary tables in HMS file includes known flows.
				5	Regression coefficients added to HMS & HOT files.
				6	Extended flows are written to HOT file.
				7	Known and observed flows and precip in HOT file.
				8	Results for each search cycle are written to HMS file.
				9	Includes results for each iteration of Newton formula.
				10	Flow comparison after FX record adjustments.
<i>Computations to be Performed</i>					
8	37-40	FE(2)	I4	blank,0	Extension with parameters provided on input records.
				1, 5	Calibration optimization for low flows.
				2, 6	Calibration optimization for medium flows.
				3, 7	Calibration optimization for high flows.
				4,8	Calibration optimization for flood flows.
				9,10	Calibration for non-flood and flood flows.
				11	Calibration without reference to flow range.
<i>Parameters of the Flow Model</i>					
9	41-44	FE(3)	I4	0, -1, 1, 2	X(i,1) Blank or zero means optimize (calibrate)
10	45-48	FE(4)	I4	0, -1, 1, 2	X(i,2) A -1 sets the parameter equal to 0.0.
11	49-52	FE(5)	I4	0, -1, 1, 2	X(i,3) A 1 sets the parameter equal to 1.0.
12	53-56	FE(6)	I4	0, -1, 1, 2	X(i,4) A 2 means the parameter is assigned a value
13	57-60	FE(7)	I4	0, -1, 1, 2	X(i,5) by an input record or by a automatic default.
14	61-64	FE(8)	I4	blank,0	Monthly-varying baseflow B(m) is not activated.
				1	B(m) are optimized subject to maximum limit BF.
				2	B(m) are set by input records or automated estimates.
15	65-68	FE(9)	I4	blank,0	Baseflow multiplier factor BX has default of 1.0.
				1	BX is optimized within range $0.0 \leq BX \leq 1.0$

## FE Record – Continuation of Flow Extension Record

field	columns	variable	format	value	description
16	69-76	BF	F8.0	+ blank,0	Constant baseflow or maximum limit on baseflow. Optional BF feature is not activated.
17	77-84	DXX	F8.0	+ blank,0 -1 -2 -3 -4	Fixed constant drought index multiplier factor DX. Previous DX in computer memory or default of 1.0. DX is optimized based on low flow OF. DX is optimized based on complete OF. DX is optimized based on number months below ZU. Drought index DI(t) is deactivated. DX is zero.
18	85-92	U(1)	F8.0	+ blank,0	Multiplier factor U(1). Extension default = 1.0 Multiplier factor U(1) is optimized.
19	93-100	U(2)	F8.0	+ blank,0	Exponent U(2). Extension (FE(2)=0) default = 1.0 Exponent U(2) is optimized.

## FN Record – Optional Names Used for Labels in HMS, HOT, and DSS Files

field	columns	variable	format	value	description
1	1-2	CD	A2	FE	Record identifier
2	3-24	FEN	A22	AN	Label printed in HMS and HOT output files.
3	25-42	FEN2	A16	AN	First part of pathname used with DSS output file.

The optional *FN* record, if used, follows directly after the *FE* record. FEN is a label of up to 22 characters used as an identifier in the HMS and HOT files. FEN2 is a label of up to 16 characters that is assigned for part A the DSS pathname used in HEC-DSSVue. The FEN2 default is the filename root. The FEN and FEN2 labels provide convenient identification to facilitate reading output but do not affect computations.

### Explanation of FE Record Fields

The *FE* record extends naturalized flows at the control point cited in *FE* record field 2. Naturalized flows  $Q(t)$  are estimated based on known naturalized flows, precipitation, and evaporation using the following equation with parameters  $U(1)$ ,  $U(2)$ ,  $BX$ ,  $DX$ ,  $B(m)$  and  $X(i,j)$ .

$$Q(t) = B(m)DI(t)BX + U(1) \left( \sum_{i=1}^N \left[ P(i,t) - X(i,1)P(i,t)^{X(i,2)} - X(i,3)E(i,t) + PP(i,t-1) - X(i,4)PP(i,t-1)^{X(i,5)} \right] \right)^{U(2)}$$

**Field 2:** The control point identifier of the location of the naturalized flows  $Q(t)$  connects to *CP* records in the HIN file and *IN* records in the FLO file.

**Fields 3 and 4:** Flows  $Q(t)$  are synthesized for the extension period defined by fields 3 and 4. With fields 3 and/or 4 blank, flow extension computations are not performed.

**Fields 5 and 6:** Parameter calibration is based on naturalized flows from a FLO file (or DSS file) and precipitation and evaporation rates from the PPP and EEE files (or DSS file) covering the period from YRBEG through YREND. The period-of-analysis defined by YRST and NYRS entered in *JC* record fields 2 and 3 serve as both defaults and limits for YRBEG and YREND. Calibration can be performed with or without activating the extension with fields 3 and 4 entries.

**Field 7:** More information is generally recorded in the output files with higher numbered FE(1) options. Options 2 and 3 provide summary tables in the HMS file and creates records in the HOT file. Option 5 includes a table in the HOT file with known and computed flows and total precipitation volumes. Options 6 and 7 are used only to explore the details of the optimization algorithm. FE(1) option 6 can generate a large HMS file and option 7 generates a much larger HMS file. With options 2 through 7 in effect, the summary tables compare computed flows after flow adjustments with known flows. With option 8, computed flows before *FX* record adjustments are compared with flows after these adjustments.

Extended flows developed by this *FE* record for this control point are added to the complete set of flows for all control points in a file controlled by JC(8) in *JC* record field 12. The flows can also be recorded separately for this control point in the HOT file using FE(1) option 4.

**Field 8:** FE(2) options control whether the automated parameter calibration optimization procedure is based on low, medium, high, or flood flows and whether sets of parameters are applied in combination (options 5,6,7,8,10) or independently (options 1,2,3,4,9,11). The weighting factors on the *FP* record provide a corresponding appropriate objective function. A blank *FE* record field 8 (FE(2)=0) means that the flow extension is performed with parameters provided on input records, and calibration routines are not activated. The flow extension with or without calibration is activated by specifying an extension period in *FE* record fields 3 and 4.

**Fields 9-13:** *FE* record fields 9-13 dealing with are calibrating parameters  $X(i,j)$  are relevant only if calibration is activated by *FE* record field 8. With a 2 entered in *FE* record fields 9-13, parameters are assigned fixed values either from input records or the initial values computed within *HYD*. A -1 or 1 entered in a field assigns a value of 0.0 or 1.0, respectively, to the particular parameter. This allows some parameters can be fixed while others are optimized.

**Fields 14:** A method for assigning values to the 12 B(m) is selected along with B(m) activation.

**Fields 15:** BX is the BX(z) parameter in the model which can also be entered on a *BX* record.

**Field 16:** With FE(8) option 1 activated, BF is a maximum limit on the B(m) in the calibration process. Otherwise BF is a constant value for all twelve B(m), and a *BM* record is not required.

**Field 17:** The drought index multiplier factor DX in the base flow component of the flow model can be set at any positive number entered in *FE* record field 17. There is a single DX with no variation between flow zones. DX defaults to 1.0 if field 17 is blank. The drought index is set at 1.0 and thus deactivated if -4.0 is entered for DX in *FE* record field 17. Three alternative DX calibration options with different objective functions can also be activated.

**Fields 18-19:** With the automated calibration procedure activated, the flow model parameters U(1) and U(2) are either input in *FE* record fields 18 and 19, default to 1.0, or are calibrated in the automated optimization procedure. In extension mode with FE(2) set at 0 (blank *FE* field 8), U(1,z) and U(2,z) are entered on the *UB* record.

## FP Record – Flow Parameter Calibration Record

field	columns	variable	format	value	description	
1	1-2	CD	A2	FP	Record identifier	
<i>Objective Function Weighting Factors</i>						
2	3-8	W1	F4.0	+	Weighting factor for Z1	Default = 0.0
3	9-12	W2	F4.0	+	Weighting factor for Z2	Default = 0.0
4	13-16	W3	F4.0	+	Weighting factor for Z3	Default = 0.0
5	17-20	W4	F4.0	+	Weighting factor for Z4	Default = 0.0
6	21-24	W5	F4.0	+	Weighting factor for Z5	Default = 0.0
7	25-28	W6	F4.0	+	Weighting factor for Z6	Default = 0.0
8	29-32	W7	F4.0	+	Weighting factor for Z7	Default = 0.0
9	33-36	W8	F4.0	+	Weighting factor for Z8	Default = 0.0
10	37-40	W9	F4.0	+	Weighting factor for Z9	Default = 0.0
11	41-44	W10	F4.0	+	Weighting factor for Z10	Default = 0.0
12	45-48	W11	F4.0	+	Weighting factor for Z11	Default = 0.0
13	49-52	W12	F4.0	+	Weighting factor for Z12	Default = 0.0
14	53-56	W13	F4.0	+	Weighting factor for Z13	Default = 1.0 or 0.0
15	57-60	W14	F4.0	+	Weighting factor for Z14	Default = 1.0 or 0.0
16	61-64	W15	F4.0	+	Weighting factor for Z15	Default = 1.0 or 0.0
17	65-68	W16	F4.0	+	Weighting factor for Z16	Default = 1.0 or 0.0
<i>Objective Function Exponents</i>						
18	69-72	ZE1	F4.0	+	Exponent for Z1-Z12	Default = 2.0
19	73-76	ZE2	F4.0	+	Exponent for Z13-Z16	Default = 2.0
<i>Enumeration Algorithm for Initial Estimates</i>						
20	77-80	FE(10)	I4	blank,0,1	Second stage enumeration with 13 steps of 0.01.	
				2	Second stage enumeration with 19 steps of 0.01.	
				3	Second stage enumeration with 9 steps of 0.02.	
				4	First stage enumeration with no second stage.	
				5	Alternative method replaces enumeration.	
				6	The enumeration algorithm is not applied and likewise option 5 is not applied.	
21	81-84	FE(11)	I4	blank,0,1	The enumeration aggregates all quadrangles.	
				2	Different parameter values for each of quadrangle.	
<i>Univariate Gradient Search Options</i>						
22	85-88	FE(12)	I4	+	Maximum limit on number of cycles. Default = 500	
23	89-96	FEX(1)	F8.0	blank,+	$\Delta x$ for B(m) adjustments as a fraction of B(m)	
24	97-104	FEX(2)	F8.0	blank,+	$\Delta x$ for X(i,j) adjustments as a fraction of X(i,j)	

The *FP* record is applicable solely for parameter calibration, not flow extension computations. Defaults for all *FP* record fields are activated if a *FP* record is not included in the HIN file.

### Explanation of FP Record Fields

**Fields 2-17:** The objective function OF in the automated parameter calibration optimization procedure is a weighted combination of Z metrics. Defaults are 1.0 for W13, W14, W15, and

W16 and zero for the other W factors if there is no *FP* record or if all 16 fields are blank. If one or more of fields 2-17 are non-zero, all other W's including W13, W14, W15, and W16 default to 0.0.

$$\begin{aligned}
 & \begin{array}{cccc} \text{low flows} & \text{medium} & \text{high} & \text{flood flows} \end{array} \\
 \text{OF} = & \text{W1} \times \text{Z1} + \text{W2} \times \text{Z2} + \text{W3} \times \text{Z3} + \text{W4} \times \text{Z4} + \\
 & \text{W5} \times \text{Z5} + \text{W6} \times \text{Z6} + \text{W7} \times \text{Z7} + \text{W8} \times \text{Z8} + \\
 & \text{W9} \times \text{Z9} + \text{W10} \times \text{Z10} + \text{W11} \times \text{Z11} + \text{Z12} \times \text{Z12} + \\
 & \text{W13} \times \text{Z13} + \text{W14} \times \text{Z14} + \text{W15} \times \text{Z15} + \text{W16} \times \text{Z16} \\
 \\
 \text{Z1} = \text{Z2} = \text{Z3} = \text{Z4} = & \left( \frac{1}{K} \right) \sum_{t=1}^K \left( \frac{100 \times |Q(t)_{\text{known}} - Q(t)_{\text{computed}}|}{\overline{Q(t)_{\text{known}}}} \right)^{E1} \\
 \\
 \text{Z5} = \text{Z6} = \text{Z7} = \text{Z8} = & \left( \frac{1}{K} \right) \sum_{t=1}^K \left( \frac{100 \times |Q(t)_{\text{known}} - Q(t)_{\text{computed}}|}{\text{ZZZ}} \right)^{E1} \\
 & \text{where ZZZ is the greater of } Q(t)_{\text{known}} \text{ or } Q(t)_{\text{computed}} \\
 \\
 \text{Z9} = \text{Z10} = \text{Z11} = \text{Z12} = & |N_K - N_C|^{E1} \\
 \\
 \text{Z13} = \text{Z14} = \text{Z15} = \text{Z16} = & \left( \frac{1}{K} \right) \frac{\left( 100 \times \left| \sum_{t=1}^K Q(t)_{\text{known}} - \sum_{t=1}^K Q(t)_{\text{computed}} \right| \right)^{E2}}{\overline{Q_{\text{known}}}}
 \end{aligned}$$

**Field 18-19:** The exponents E1 and E2 in the Z equations have a default of 2.0 that can be changed with ZE1 and ZE2.

**Field 20:** Initial estimates of the values for the decision variables (calibration parameters) are assigned prior to starting the univariate gradient search algorithm. With FE(10) option 6, values provided on input records or stored in computer memory from preceding *FE* record computations may be adopted for these initial estimates. Otherwise, the initial estimates are developed automatically within *HYD* as specified by FE(10) in *FP* record field 20. FE(10) options 1, 2, 3, and 4 activate alternative versions of an enumeration strategy for computing initial values for U(1), U(2), X(i,1), X(i,3), X(i,4), B(m), and BX. Option 5 is an alternative method that requires less computer execution time but is much more approximate.

The enumeration procedure has two stages. The stage 1 enumeration interval is 0.1. The stage 2 interval varies between options. Options 1, 2, and 3 apply both stages. Option 4 applies only the first stage. The first stage enumeration is the same for options 1, 2, 3, and 4, but the second stage differs. Options 5 and 6 switch to other different approaches with no enumeration.

**Field 21:** FE(11) in *FP* record field 21 specifies whether the same or different initial estimates of X(i,1), X(i,3), and X(i,4) values are computed for the different quadrangles in the enumeration algorithm. In applying the enumeration algorithm to develop initial parameter estimates, FE(11)

option 1 assumes that all quadrangles have the same values for the  $X(i,j)$ . FE(11) option 2 computes separate initial estimates of  $X(i,1)$ ,  $X(i,3)$ , and  $X(i,4)$  for each of ND minus 1 quadrangles. Regardless of FE(11) option, the subsequent univariate gradient search always treats the  $X(i,1)$ ,  $X(i,2)$ ,  $X(i,3)$ ,  $X(i,4)$ , and  $X(i,5)$  as multiple decision variables that may vary between quadrangles. Computer runtime may vary from several minutes to many hours between the alternative FE(10) and FE(11) options. FE(11) option 2 greatly increases computer runtime. FE(11) option 2 is relevant only for control points with more than one quadrangle.

N denotes the number of quadrangles listed on the *QD* record. The first ND quadrangles listed comprise a subset of the N quadrangles. ND and N are entered in *QD* record fields 2 and 3. If *QD* record field 2 is blank or zero, ND defaults to N. The parameter ND is used for two different unrelated purposes: (1) enumeration options and (2) drought index computations. With FE(11) option 2, there are ND enumerations. The first ND less one quadrangles are each enumerated separately. The NDth enumeration combines all remaining quadrangles. Thus, FE(11) option 1 is equivalent to FE(11) option 2 with ND set at 1. For example, with ND of 4 and N of 7, the first 3 quadrangles listed on the *QD* record are each enumerated individually. The fourth enumeration applies to the remaining four quadrangles.

**Field 22:** A search cycle in the automated univariate gradient search optimization procedure consists of adjusting each of the decision variables. The cyclic computations continue until stop criteria are satisfied. One component of the stop criteria is a maximum limit FE(12) on the number of cycles. The default limit is 500 cycles.

**Field 23 and 24:** Step sizes  $\Delta x$  are required in the computation of the first and second derivatives  $f'(x)$  and  $f''(x)$  for the Newton formula. The defaults for  $\Delta x$  described below are normally recommended but experimentation with alternative  $\Delta x$  may be of interest.

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

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

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

The step size  $\Delta x$  is set within *HYD* by multiplying the value of  $B(m)$  or  $X(i,j)$  computed in the preceding cycle by FEX(1) or FEX(2).

$$\Delta x = \text{greater of FEX(1)} \times B(m) \text{ or } 1.0 \text{ acre-foot/month}$$

$$\Delta x = \text{greater of FEX(2)} \times X(i,j) \text{ or } 0.000001$$

**Field 23:** The  $\Delta x$  used in optimizing  $B(m)$  can be set with FEX(1) in *FP* record field 23. With *FP* record field 23 blank, the default  $\Delta x$  applied by *HYD* is the maximum of:

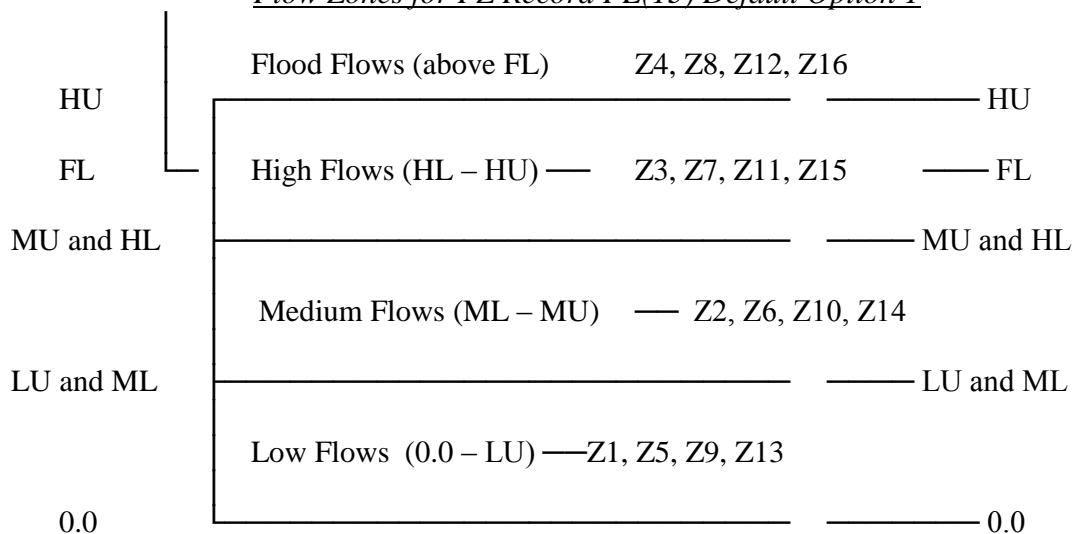
$$\Delta x = 0.001 \times B(m) \text{ or } \Delta x = 5.0 \text{ acre-feet/month}$$

**Field 24:** The  $\Delta x$  used in optimizing  $X(i,j)$  can be set with FEX(2). With *FP* field 24 blank, the default  $\Delta x$  applied by *HYD* is  $0.05 \times X(i,j)$  during a preliminary set of cycles changing to  $0.001 \times X(i,j)$  for the remaining cycles, with a minimum limit on  $\Delta x$  of 0.000001.

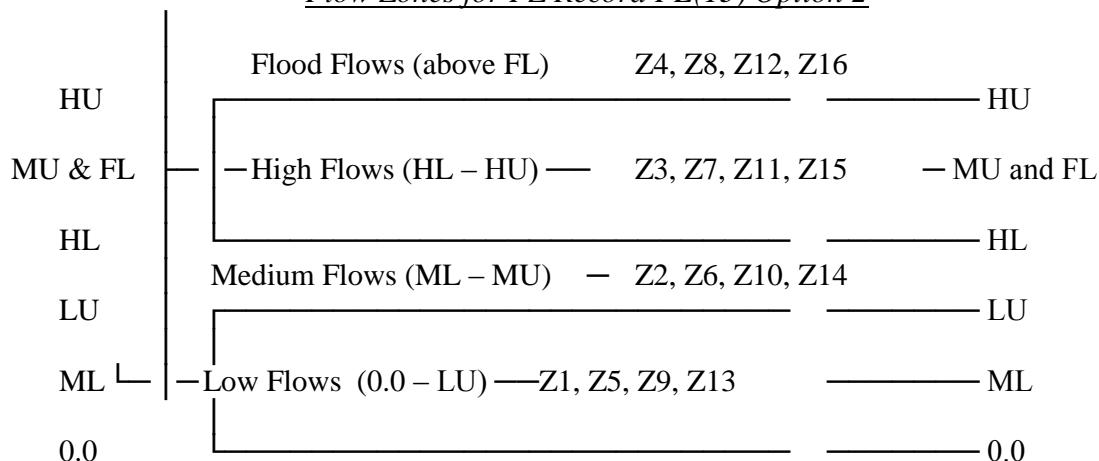
## FZ Record – Flow Zones

field	columns	variable	format	value	description
1	1-2	CD	A2	FE	Record identifier
2	3-8	FE(13)	I6	blank,0,1 2	Low, medium, and high are combined as one zone. All four zones are used.
3	9-16	ZU	F8.0	+	HMS file includes count of number of months with flow at or below ZU. DXX option 3 uses this count.
<i>Limits Defining Low, Medium, High, Flood Flows</i>					
4	17-24	LU	F8.0	+	Upper limit on low flow zone. Default LU=0.0
5	25-32	ML	F8.0	+	Lower limit on medium flow zone. Default ML=LU
6	33-40	MU	F8.0	+	Upper limit on medium flow. Default = 99,900,000.
7	41-48	HL	F8.0	+	Lower limit on high flow zone. Default HL=MU
8	49-56	HU	F8.0	+	Upper limit on high flow zone. Default=99,900,000.
9	57-64	FL	F8.0	+	Lower limit on flood flow zone. Default FL=HU

### Flow Zones for FZ Record FE(13) Default Option 1



### Flow Zones for FZ Record FE(13) Option 2



## FR Record – Flow Ranges

field	columns	variable	format	value	description
1	1-2	CD	A2	FE	Record identifier
2	3-8	QK	I6	blank, 0, 1 2	One single FR record is used.. Two FR records are used. A second <i>FR</i> record follows directly after this <i>FR</i> record.
<i>Ranges for FR(r) on FX record.</i>					
3	9-16	QR(1)	F8.0	+	Flow volume with 95% exceedance frequency.
4	17-24	QR(2)	F8.0	+	Flow volume with 90% exceedance frequency.
5	25-32	QR(3)	F8.0	+	Flow volume with 80% exceedance frequency.
6	33-40	QR(4)	F8.0	+	Flow volume with 70% exceedance frequency.
7	41-48	QR(5)	F8.0	+	Flow volume with 60% exceedance frequency.
8	49-56	QR(6)	F8.0	+	Flow volume with 50% exceedance frequency.
9	57-64	QR(7)	F8.0	+	Flow volume with 40% exceedance frequency.
10	65-72	QR(8)	F8.0	+	Flow volume with 30% exceedance frequency.
11	73-80	QR(9)	F8.0	+	Flow volume with 20% exceedance frequency.
12	81-88	QR(10)	F8.0	+	Flow volume with 10% exceedance frequency.
13	89-96	QR(11)	F8.0	+	Flow volume with 5% exceedance frequency.

QR(r) are 11 flow volumes in acre-feet/month entered on a *FR* record that define 12 flow ranges used for the FX(r) on the *FX* record and the RBA on the *RC* record. The QR(r) must increase from small to large with Q(1) being the smallest volume increasing to QR(11) being the largest. Monthly flow volumes with exceedance frequencies listed in the description column of the table above are suggested but other flow volumes can also be adopted. Up to 11 QR(r) may be entered on a *FR* record to define up to 12 flow ranges. However, fewer than 12 ranges may be defined. For example, the number of flow ranges may be reduced to accommodate sites with a large number of months with zero flows.

A *FR* record is required if a *FX* record is included in the HIN file in order to define the ranges (r) for which the multiplier factors FX(r) are applied. A *FR* record can also be used with or without a *FX* record to include mean flow ratios in the tables in the message HMS file.

A 2 entered in field 2 of the first *FR* record means that a second *FR* record follows. Two *FR* records are used in the level 2 calibration process. The first *FR* record contains known flow volumes associated with specified exceedance frequencies. The second *FR* record contains computed flow volumes associated with the same exceedance frequencies as the first *FR* record. *HYD* computes ratios of mean known to mean computed flows and records these ratios on a *FX* record as multiplier factors FX(r) to be applied in the final flow extension.

The *FE* record for the final flow extension has a *FX* record and the corresponding *FR* record for computed flows. There is only one *FR* record applied, which is the second *FR* record used in the level 2 calibration which is based on level 1 computed flows.

**BM** Record – Base Flows**B1, B2, B3, and B4** Records – Base Flows for Low, Medium, High, and Flood Flows

field	columns	variable	format	value	description
1	1-2	CD	A2	B_	Record identifier
2	3-8		6x		Field is not used.
3	9-16	BM(1)	F8.0	+	Parameter B(1) in flow equation for month 1
4	17-24	BM(2)	F8.0	+	Parameter B(2) in flow equation for month 2
5	25-32	BM(3)	F8.0	+	Parameter B(3) in flow equation for month 3
6	33-42	BM(4)	F8.0	+	Parameter B(4) in flow equation for month 4
7	43-48	BM(5)	F8.0	+	Parameter B(5) in flow equation for month 5
8	49-56	BM(6)	F8.0	+	Parameter B(6) in flow equation for month 6
9	57-64	BM(7)	F8.0	+	Parameter B(7) in flow equation for month 7
10	65-72	BM(8)	F8.0	+	Parameter B(8) in flow equation for month 8
11	73-80	BM(9)	F8.0	+	Parameter B(9) in flow equation for month 9
12	81-88	BM(10)	F8.0	+	Parameter B(10) in flow equation for month 10
13	89-96	BM(11)	F8.0	+	Parameter B(11) in flow equation for month 11
14	97-104	BM(12)	F8.0	+	Parameter B(12) in flow equation for month 12

In calibration mode, *BM*, *B1*, *B2*, *B3*, and *B4* records are created automatically by *HYD* to record the B(m) resulting from the calibration process. The 12 monthly calibrated values for the parameters B(m) of the flow equation are applied in the later executions of *HYD* to extend flows. *B1*, *B2*, *B3*, and *B4* records contain separate parameters for low flows, medium flows, high flows, and flood flows, respectively. The *BM* record is for the non-flood flows for the default *FZ* record FE(13) option 1 and for applications in which flows are modeled without separate parameters for low, medium, high, and flood flows.

During an execution of *HYD* with calibration features activated, relevant *BM*, *B1*, *B2*, *B3*, *B4*, *XP*, *X1*, *X2*, *X3*, and *X4* records are automatically created in the *HYD* output HOT file whenever *FE* record FE(1) is set at option 2 or larger numbered options. These records are then manually inserted (editor cut and paste) into an input *HIN* file for extending flows.

**XP** Record – Rainfall-Runoff  $X(i,j)$  Coefficients**X1, X2, X3, X4** Records – Rainfall-Runoff Coefficients for Low, Medium, High, Flood Flows

field	columns	Variable	format	value	description
1	1-2	CD	A2	XP	Record identifier
2	3-8	QID	I6	+	Quadrangle identifier
3	9-16	$X(i,1)$	F12.0	+	Multiplier factor for $P(i,t)$ in flow equation
4	17-24	$X(i,2)$	F12.0	+	Exponent for $P(i,t)$ in flow equation
5	25-32	$X(i,3)$	F12.0	+	Multiplier factor for $E(i,t)$ in flow equation
6	33-40	$X(i,4)$	F12.0	+	Multiplier factor for $PP(i,t-1)$ in flow equation
7	41-48	$X(i,5)$	F12.0	+	Exponent for $PP(i,t-1)$ in flow equation

In calibration mode, values for the 5N parameters  $X(i,j)$  in the flow equation are recorded automatically by *HYD* on either *XP* records or *X1*, *X2*, *X3*, and *X4* records for low, medium, high, and flood flows, respectively. The *XP* record is for non-flood flows for *FZ* record default FE(13) option 1 or for applications in which flows are modeled without separate parameters for low, medium, high, and flood flows. *X1*, *X2*, *X3*, and *X4* records provide separate  $X(i,j)$  are for low, medium, high, and flood flows. A set of records is developed and applied for each quadrangle. In flow extension mode, these records are input in the *HIN* file.

*XP*, *X1*, *X2*, *X3*, and *X4* records are created automatically by *HYD* in the calibration process to record the parameters  $X(i,j)$  of the flow equation for use in the later executions of *HYD* to extend flows. During an execution of *HYD* with calibration features activated and *FE* record FE(1) option 2 or larger numbered options selected, relevant *BM*, *B1*, *B2*, *B3*, *B4*, *XP*, *X1*, *X2*, *X3*, and *X4* records are automatically created in the *HYD* output *HOT* file. These records are then manually inserted (cut and paste) into an input *HIN* file for extending flows.

## UB Record – Model Parameters for Flow Extension

field	columns	variable	format	value	description
1	1-2	CD	A2	UB	Record identifier
2	3-8	ZF(1)	F6.0	+	Maximum flow limit for near-zero flow adjustment.
3	9-16	ZF(2)	F8.0	+	Monthly volume subtracted from near-zero flows.
4	17-24	UX(1)	F8.0	+	First or low flow multiplier factor. Default = 1.0
5	25-32	UE(1)	F8.0	+	First or low flow model exponent. Default = 1.0
6	33-40	BX(1)	F8.0	+	First or low flow base flow factor. Default = 1.0
7	41-48	UX(4)	F8.0	+	Last or flood flow multiplier factor. Default = 1.0
8	49-56	UE(4)	F8.0	+	Last or flood flow model exponent. Default = 1.0
9	67-64	BX(4)	F8.0	+	Last or flood flow base flow factor. Default = 1.0
10	65-72	UX(2)	F8.0	+	Medium flow model multiplier factor. Default = 1.0
11	73-80	UE(2)	F8.0	+	Medium flow model exponent. Default = 1.0
12	81-88	BX(2)	F8.0	+	Medium flow base flow factor. Default = 1.0
13	89-96	UX(3)	F8.0	+	High flow model multiplier factor. Default = 1.0
14	97-104	UE(3)	F8.0	+	High flow model exponent. Default = 1.0
15	105-112	BX(3)	F8.0	+	High flow base flow factor. Default = 1.0

The purpose of ZF(1) and ZF(2) in *UB* record fields 2 and 3 is to improve capabilities for appropriately generating zero and near-zero flows. The quantity ZF(2) is subtracted from all computed flows that have volumes of ZF(1) or less. ZF(1) and ZF(2) have units of acre-feet/month and defaults of 0.0. ZF(1) and ZF(2) are determined and added to the *UB* record during the level 2 calibration process.

UX(z) and UE(z) are the multiplier factor U(1,z) and exponent U(2,z) of the flow model. BX(z) is the base flow multiplier factor BX in the flow model. The index z refers to flow zones. These parameters are determined during the level 1 calibration process.

Flow zones are defined by the *FZ* record. The parameter FE(13) in *FZ* record field 2 specifies two alternative options for defining flow zones. With the default FE(13) option 1, parameters are provided for two zones consisting of the flood flow zone and a second zone combining the low, medium, and high flow zones. The parameters UX(z=1,4), UE(z=1,4), and BX(z=1,4) are provided on the *UB* record for FE(13) option 1. FE(13) option 2 consists of using four flow zones. The parameters UX(z=1,2,3,4), UE(z=1,2,3,4), and BX(z=1,2,3,4) are provided on the *UB* record for FE(13) option 2.

## FX Record – Flow Adjustment Factors

field	columns	variable	format	value	description
1	1-2	CD	A2	FX	Record identifier
2	3-8	FX(13)	F8.0	+	Multiplier factor applied to all of the computed flows.
3	33-40	FX(1)	F8.0	+	Multiplier factor for range 1 (0.0 ≤ Q < Q95%)
4	41-48	FX(2)	F8.0	+	Multiplier factor for range 2 (Q95% ≤ Q < Q90%)
5	49-56	FX(3)	F8.0	+	Multiplier factor for range 3 (Q90% ≤ Q < Q80%)
6	57-64	FX(4)	F8.0	+	Multiplier factor for range 4 (Q80% ≤ Q < Q70%)
7	65-72	FX(5)	F8.0	+	Multiplier factor for range 5 (Q70% ≤ Q < Q60%)
8	73-80	FX(6)	F8.0	+	Multiplier factor for range 6 (Q60% ≤ Q < Q50%)
9	81-88	FX(7)	F8.0	+	Multiplier factor for range 7 (Q50% ≤ Q < Q40%)
10	89-96	FX(8)	F8.0	+	Multiplier factor for range 8 (Q40% ≤ Q < Q30%)
11	97-104	FX(9)	F8.0	+	Multiplier factor for range 9 (Q30% ≤ Q < Q20%)
12	105-112	FX(10)	F8.0	+	Multiplier factor for range 10 (Q20% ≤ Q < Q10%)
13	113-120	FX(11)	F8.0	+	Multiplier factor for range 11 (Q10% ≤ Q < Q5%)
14	121-128	FX(12)	F8.0	+	Multiplier factor for range 12 (Q5% ≤ Q)

Without the optional *FX* record, FX(13) and the 12 FX(r) default to 1.0. Blank fields on the *FX* record default to 1.0. A −1.0 assigns a zero to FX(13) and the 12 FX(r).

*FX* records can be created manually with user specified values for FX(13) and the 12 FX(r). However, *FX* records with a blank field 2 are created automatically by *HYD* during the level 2 calibration process. The FX(r) ratios on a *FX* record are also included in the summary tables in the message HMS file. FX(13) is entered manually in *FX* record field 2.

All of the computed flows are multiplied by FX(13) as a last step in the flow extension computations. FX(13) is applied after application of the 12 FX(r). FX(13) is designed to be manually added to the *FX* record as the last step in the level 2 parameter calibration. FX(13) defaults to 1.0 if *FX* record field 2 is blank. In many or most applications, the FE(13) default of 1.0 will be adopted. If not defaulted to 1.0, FX(13) will normally be a flow ratio used to replicate mean flows.

The *FR* and *FX* records are designed to be developed during the level 2 calibration process based on comparing frequency relationships for computed and known flows. In the flow extension computations, the computed flows falling within each of the twelve flow ranges defined on the eleven QR(r) on the *FR* record are multiplied by the FX(r) factors from the *FX* records.

Normally, only one *FX* record will be applied at a particular control point. However, *HYD* allows any number of *FX* records to be assigned to the same control point, with all of the *FX* records connected to the same *FR* record. The multiplier factors from all of the *FX* records are applied to the computed flows at the control point.

## RC Record – Regression Coefficients

field	columns	variable	format	value	description
1	1-2	CD	A2	RC	Record identifier
2	3-8	RBA	I6	blank,0,11	Power regression equation for all flows
				12	Linear regression equation for all flows
				1	Flow boundary = QR(1) from FR record field 3
				2	Flow boundary = QR(2) from FR record field 4
				3	Flow boundary = QR(3) from FR record field 5
				4	Flow boundary = QR(4) from FR record field 6
				5	Flow boundary = QR(5) from FR record field 7
				6	Flow boundary = QR(6) from FR record field 8
				7	Flow boundary = QR(7) from FR record field 9
				8	Flow boundary = QR(8) from FR record field 10
				9	Flow boundary = QR(9) from FR record field 11
				10	Flow boundary = QR(10) from FR record field 12
				11	Flow boundary = QR(11) from FR record field 13
3	33-40	AC(1)	F8.0	+	Coefficient A for power regression in lower range
4	41-48	BC(1)	F8.0	+	Coefficient B for power regression in lower range
5	49-56	AC(2)	F8.0	+	Coefficient A for linear regression in upper range
6	57-64	BC(2-)	F8.0	+	Coefficient B for linear regression in upper range

FE record FE(1) option 3 combined activates a routine that performs a regression analysis of known flows  $Q$  versus computed flows  $Q_C$ . The resulting regression coefficients are provided on *RC* records automatically created in the HOT file. The regression coefficients along with correlation coefficients are also tabulated in the HMS file. The *RC* records may be included in the HIN dataset used to extend the flows.

$Q_C$  are the flows in acre-feet/month computed with the flow model with previously calibrated values of the parameters. The  $Q$  are new improved estimates of the flows. The following power regression equation is applied to the  $Q_C$  that are less than 90% of the regression boundary flow RBF specified in *RC* record field 2.

$$Q = A \times Q_C^B$$

The following linear regression equation is applied to the  $Q_C$  that are greater than 110% of RBF.

$$Q = A + B \times Q_C$$

For  $Q_C$  that fall between 90% and 110% of the RBF ( $0.9RBF \leq Q_C \leq 1.1RBF$ ),  $Q$  is computed as the average of the two values determined with the linear and power regression equations.

The coefficients  $A$  and  $B$  in the power equation are provided as AC(1) and BC(1) in *RC* record fields 3 and 4. The coefficients  $A$  and  $B$  in the linear equation are provided as AC(2) and BC(2) in *RC* record fields 5 and 6.

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