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Water Rights Analysis Package (WRAP) Daily Modeling System

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Texas Water Resources Institute
make every drop count

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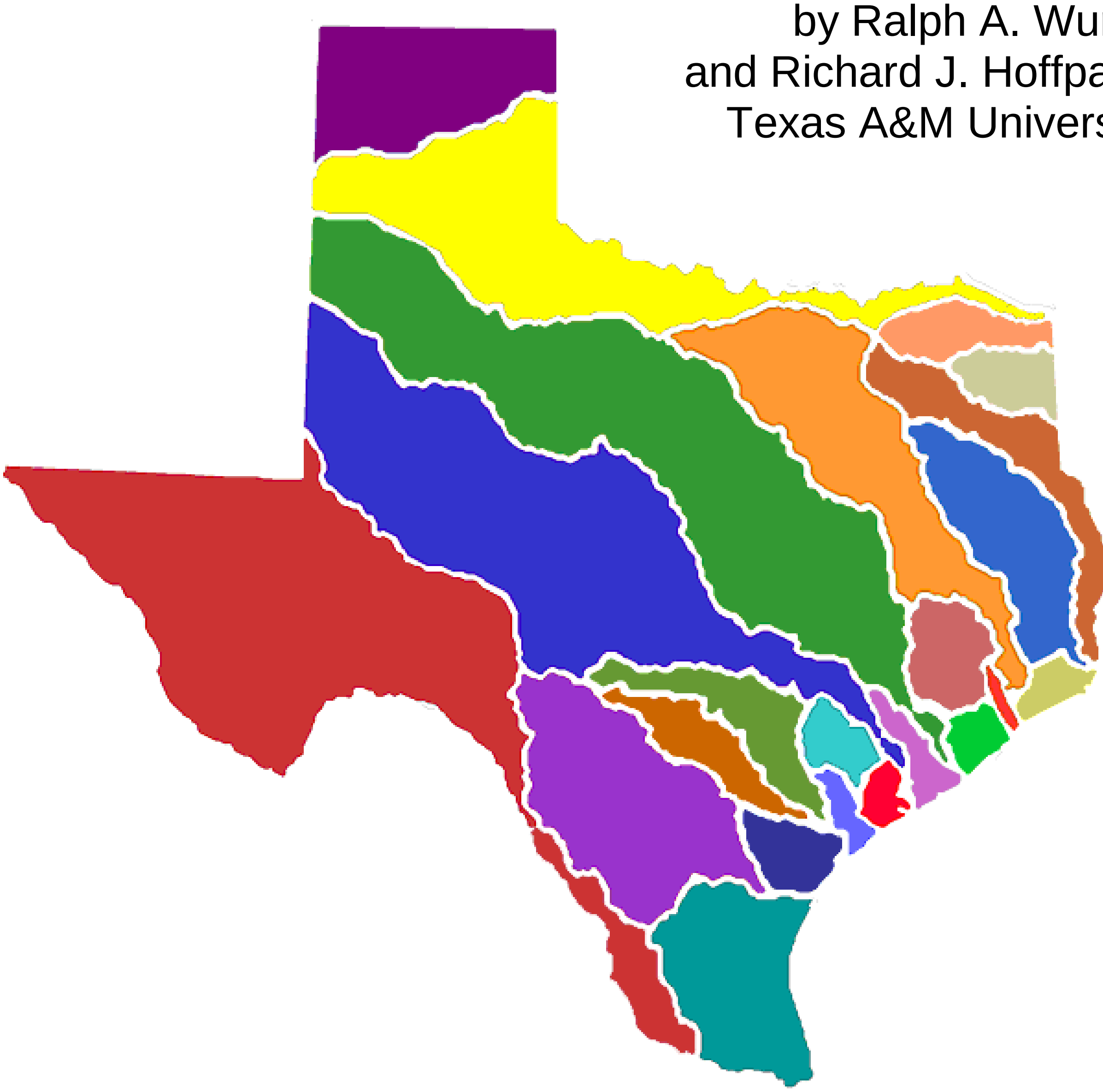

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for the

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CHAPTER 1
WATER RIGHTS ANALYSIS PACKAGE (WRAP) MODELING SYSTEM

WRAP is a generalized river/reservoir system simulation model providing flexible capabilities for analyzing water resources development, management, control, allocation, and use. The Texas Commission on Environmental Quality (TCEQ) Water Availability Modeling (WAM) System combines WRAP with input datasets for the river basins of the state. The WRAP modeling system documented by the basic *Reference* and *Users Manuals* was originally developed based on a monthly computational time step. The TCEQ WAM System WRAP input datasets were developed and are routinely applied using a monthly time step. This *Daily Modeling System Manual* documents an expanded version of WRAP that allows use of a daily or other sub-monthly time step and provides additional features for simulating flood control reservoir operations and environmental instream flow requirements.

The daily WRAP includes all of the capabilities of the monthly modeling system plus an array of additional major new features. This expanded version of WRAP allows each of the 12 months of the year to be subdivided into multiple time intervals with the default being daily. Simulation input may either include daily or other sub-monthly time interval naturalized flows or options may be activated for disaggregating monthly flows to smaller time intervals. Future time steps extending over a forecast period are considered in the simulation model in determining both water availability from a supply perspective and remaining flood control channel capacity. Routing methods reflecting flow attenuation effects are added for use with daily or other sub-monthly computational time steps. Calibration methods for determining routing parameters are included in the modeling package. The daily WRAP model system incorporates pulse flow environment instream flow requirements and reservoir operations for flood control.

WRAP Documentation

This report serves as both reference and users manuals for the features added to WRAP to convert to a daily modeling system along with providing other additional water management modeling capabilities enabled by a daily time step. This *Daily Modeling System Manual* supplements and extends the basic *Reference* and *Users Manuals*. The expanded modeling capabilities outlined here build upon the previously documented WRAP organizational structure and methodologies. The *Daily Manual* is written based on the premise that the reader is familiar with the information provided by the basic *Reference* and *Users Manuals*.

WRAP is documented by the set of manuals listed below and in the reference list on page 211. The *Reference* and *Users Manuals* cover capabilities that are reflected in the current as of August 2012 TCEQ WAM System datasets. The *Fundamentals Manual* is a condensed introduction to the basics. This *Daily Manual* along with the *Salinity Manual* and *Hydrology Manual* cover major additional WRAP features developed over the past several years that have not yet as of August 2012 been adopted in routine applications of the TCEQ WAM System.

Water Rights Analysis Package (WRAP) Modeling System Reference Manual,
TWRI TR-255, 9th Edition, August 2012. (*Reference Manual*)

Water Rights Analysis Package (WRAP) Modeling System Users Manual,
TWRI TR-256, 9th Edition, August 2012. (*Users Manual*)

Fundamentals of Water Availability Modeling with WRAP, TWRI TR-283, 6th Edition, September 2011. (*Fundamentals Manual*)

Water Rights Analysis Package (WRAP) River System Hydrology, TWRI TR-431, August 2012. (*Hydrology Manual*)

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

Water Rights Analysis Package (WRAP) Daily Modeling System, TWRI TR-430, August 2012. (*Daily Manual*)

Water Rights Analysis Package (WRAP) Modeling System Programming Manual, TWRI TR-388, 2nd Edition, August 2012. (*Programming Manual*)

WRAP Programs

WRAP consists of the computer programs listed in Table 1.1. The filenames of the executable files are shown in the second column. The third column cites the manuals that document the programs.

Table 1.1 WRAP Programs

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

The Fortran programs are compiled as separate individual programs, which may be executed independently of each other and independently of *WinWRAP*. However, *WinWRAP* facilitates running the WRAP programs within *Microsoft Windows* in an integrated manner along with use of Microsoft programs and *HEC-DSSVue* (Hydrologic Engineering Center 2009). Any and all of the programs may be executed from *WinWRAP*.

WRAP-SIM simulates the river/reservoir water allocation/management system for input sequences of monthly naturalized flows and net evaporation rates. *SIM* is limited to a monthly time step. The expanded *SIMD* (D for daily) contains all of the capabilities of the monthly time step *SIM*, plus options related to environmental instream pulse flow requirements, reservoir operations for flood control, forecasting and routing, sub-monthly targets, and synthesizing sub-monthly time step naturalized stream flows. Although any sub-monthly time interval may be used, *SIMD* is called the daily version of *SIM* since the day is the default expected to be adopted most often.

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

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

Program *TABLES* is used to organize and summarize the simulation results from *SIM*, *SIMD*, and *SALT*, including developing reliability and frequency metrics and various tabulations. *TABLES* works with either monthly or sub-monthly (daily) simulation results.

Program *SALT* is applied in combination with either *SIM* or *SIMD* to simulate salinity. *SALT* uses a monthly time step. *SALT* obtains monthly water quantities by reading the main *SIM* or *SIMD* output file, obtains water quality data by reading a salinity input file, and tracks the water quality constituents through the river/reservoir system. All of the simulation capabilities of *SIM/SIMD* are preserved while adding salt accounting capabilities. *TABLES* includes routines for organizing *SALT* simulation results as tables or DSS records, performing frequency analyses, and determining water supply diversion reliabilities with and without considerations of specified maximum allowable salinity concentrations.

WRAP-HYD assists in developing monthly naturalized stream flow and reservoir net evaporation rate data for the *SIM* hydrology input files. *HYD* capabilities for extending the hydrologic period-of-analysis include recently added routines for synthesizing sequences of monthly naturalized flows from observed monthly precipitation and evaporation rates.

The program *DAY* provides a set of computational routines that facilitate developing *SIMD* hydrology input related to sub-monthly (daily) time steps. *DAY* routines include (1) disaggregation of monthly flows to sub-monthly time intervals using routines also contained in *SIMD* and (2) calibrating routing parameters. Multiple options are provided for performing these tasks.

Modeling applications combine the generalized WRAP programs with input datasets describing specific systems of rivers, reservoirs, other constructed facilities, and water resources management/control/allocation/use requirements. Certain WRAP programs read files that have been created by other WRAP programs. The interface program *WinWRAP* facilitates connecting programs and data files within a Microsoft Windows operating system environment.

WRAP Input and Output Files

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

The *WinWRAP* interface facilitates executing programs and assigning data files. The user must create or obtain previously created files describing the hydrology and water management facilities and practices for the river basin or region of concern along with other related information. The programs are connected through input and output files. Certain programs create files with intermediate results to be read by other programs. File access occurs automatically, controlled by the software.

Table 1.2 lists the different types of WRAP input and output files. Table 1.3 is a matrix of computer programs and input/output files. All of the file types are listed including those that are and are not relevant to the modeling features covered in this *Daily Manual*. Most of the files are discussed in the *Users and Reference Manuals*.

Input and output datasets are in the format of text files, which can be read by Microsoft WordPad, NotePad, Word, and Excel and other editors such as NotePad++ (http://notepad-plus-plus.org). Program *TABLES* also provides options to convert essentially any of the simulation results produced by the *SIM*, *SIMD*, and *SALT* to HEC-DSS files, to be read with *HEC-DSSVue* (Hydrologic Engineering Center 2009, http://www.hec.usace.army.mil/) for plotting graphs or other data processing manipulations.

The names of the data files read and written by the WRAP programs are in the format *root.extension*. The root is an arbitrary name assigned by the model user. The 3-character extensions are set by naming conventions incorporated in the programs. The extensions listed in Tables 1.2 and 1.3 define the types of data contained in the files. File types are referred to by their extensions. For example, a DAT file has a filename with the extension DAT and consists of certain basic input data read by the programs *SIM* and *SIMD*. A FLO file has the filename extension FLO and contains naturalized flows.

With the exception of the program *HYD*, all files for all programs may be named with the same root. Certain files used in a single execution of a program must have the same filename root. However, as discussed in the *Fundamentals Manual*, various options allow filename roots to differ based on user preference, as indicated by the terms *root1*, *root2*, and *root3* in Table 1.2. The root for *SIM* and *SIMD* hydrology files (root2.FLO, root2.EVA, and root2.DIS) may differ from the main input data file (root1.DAT) if the user so prefers. Thus, multiple DAT files reflecting different water management scenarios may be combined with the same FLO, EVA, and DIS files representing river basin hydrology. All of these files may also have the same filename root if the user prefers.

The root for *TABLES* files may differ from *SIM/SIMD* files. Unlike the other files, user-selected filename extensions may replace the default TOU for the *TABLES* output file.

In executing the WRAP programs from *WinWRAP*, the model-user enters one or perhaps two filename roots. The software assigns the extensions automatically. Input files created with an editor must be saved with a filename with the appropriate three-character filename extension.

Table 1.2
Input and Output Files

	SIM and *SIMD* Input Files
root1.DAT	required main input file containing all input ***dat***a, except the voluminous hydrology related data contained in the following files
root2.FLO	inflow *IN* records with naturalized stream ***flo***ws (optional filename root.INF)
root2.EVA	***eva***poration *EV* records with net evaporation-precipitation rates
root2HYD.DSS	***hyd***rology DSS file with naturalized flows and evaporation-precipitation rates
root2.DIS	flow ***dis***tribution *FD* and *FC* and watershed parameter *WP* records
root2.HYD	*IN* and *EV* records provided in a single ***hyd***rology file instead of FLO and EVA files
root2.FAD	***f***low ***ad***justment *FA* records for adjusting naturalized stream flows
root1.BES	***b***eginning and/or ***e***nding ***s***torage listing activated by *JO* record field 5
root2.RUF	***r***egulated-***u***nappropriated *RU* flow adjustment records activated by *JO* field 12 or 13
	Additional SIMD Input Files
root2.DCF	***d***aily or other sub-monthly ***c***ontrol point and ***f***low data read by *SIMD*
root2.HIS	hydrologic index time series entered on *HI* records
	SIM and *SIMD* Output Files
root1.MSS	***m***e***ss***ages reporting simulation progress and input data errors
root1.OUT	main simulation results ***out***put file read by *TABLES* and *SALT*
root1.SOU	main ***s***imulation results ***ou***tput file in columnar format
root1.DSS	simulation results output file in HEC-DSS (***d***ata ***s***torage ***s***ystem) binary format
root1.HRR	***h***ydropower and ***r***eservoir ***r***elease file read by *TABLES*
root1.YRO	***y***ield-***r***eliability ***o***utput table presenting the results of a *FY*-record analysis
root1.CRM	***c***onditional ***r***eliability ***m***odeling simulation results read by *TABLES*
root1.ZZZ	changes in stream flow availability in water rights sequence activated by *ZZ* record
root1.BES	***b***eginning and/or ***e***nding ***s***torage listing activated by *JO* record field 5
root1.BRS	***b***eginning ***r***eservoir ***s***torage listing activated by *JO* record field 6 to provide beginning reservoir storage for program *SALT* and *TABLES 5CR2* record routines

Table 1.2
Input and Output Files (continued)

Additional SIMD Output Files

root1.SUB	***sub***-monthly time step simulation results
root1.AFF	***a***nnual ***f***lood ***f***requency file with annual series of peak flow and storage
root1.SMM	***s***ub-***m***onthly ***m***essages reporting simulation parameters and optional information

SALT Input Files

root2.SIN	required ***s***alinity ***in***put file with concentrations or loads of entering flows
root2.DAT	required main *SIM/SIMD* input file from which *CP* records are read
root2.OUT	required main *SIM/SIMD* ***out***put file with simulation results
root2.BRS	***b***eginning ***r***eservoir ***s***torage file created by *SIM/SIMD* and read by *SALT* to provide beginning reservoir storage if specified by *JC* record field 8
root2.BRC	***b***eginning ***r***eservoir ***c***oncentration file created by *SALT* and also read by *SALT* as specified by *JC* record field 9

SALT Output Files

root1.SAL	***sal***inity simulation results read by *TABLES*
root1.SMS	***s***alinity ***m***e***s***sage file with simulation trace, error and warning messages, and intermediate and summary simulation results tables
root1.BRC	***b***eginning ***r***eservoir ***c***oncentration file created and read by *SALT*

TABLES Input Files

root3.TIN	required ***T****ABLES* ***in***put file with specifications regarding tables to be developed
root1.DAT	*SIM/SIMD* input DAT file
root1.OUT	*SIM/SIMD* output OUT file
root1.ZZZ	*SIM/SIMD* output ZZZ file
root1.HRR	*SIM/SIMD* output HRR file
root1.DIS	*SIM/SIMD* input DIS file
root1.AFF	*SIMD* ***a***nnual ***f***lood ***f***requency output file with annual series of peak flow and storage
root1.CRM	*SIM/SIMD* ***c***onditional ***r***eliability ***m***odeling output file
root1.SFF	***s***torage-***f***low-***f***requency file created by *5CR1* record and read by *5CR2* record

TABLES Output Files

root4.TOU	***T****ABLES* ***ou***tput file with the tables developed by the various routines
oot4.TMS	***T****ABLES* ***m***e***s***sage file with tracking the computations and reporting input data errors
root4.DSS	Hydrologic Engineering Center ***D***ata ***S***torage ***S***ystem file read by *HEC-DSSVue*
root4.SFF	***s***torage-***f***low-***f***requency file created by *5CR1* record and read by *5CR2* record

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Table 1.2
Input and Output Files (continued)

<u>*HYD* Input Files</u>

root5.HIN	***H***YD file with all ***in***put data not included in the following hydrology files
root5.FLO	inflow *IN* records with stream ***flo***ws
root5.EVA	***eva***poration *EV* records with net evaporation-precipitation rates
root5.DIS	flow ***dis***tribution *FD & FC* and watershed parameter *WP* records
root5.HYD	*IN* and *EV* records in single ***hyd***rology file in modified format
root5.DSS	***D***ata ***S***torage ***S***ystem file of stream flows and evaporation-precipitation depths

<u>*HYD* Output Files</u>

root6.HOT	***H***YD ***o***u***t***put file with all output not included in the following files
root6.HMS	***H***YD ***m***e***s***sage file tracking the computations and reporting input data errors
root6.FLO	inflow *IN* records with naturalized stream ***flo***ws
root6.EVA	***eva***poration *EV* records with net evaporation-precipitation rates
root6.DSS	***D***ata ***S***torage ***S***ystem file of stream flows and evaporation-precipitation depths

<u>*DAY* Input Files</u>

root1.DIN	main ***DAY*** ***in***put file
root2.FLO	input file of monthly ***flo***ws in either *IN* record or columnar format
root2.DCF	input file of ***d***aily ***f***lows in either *DF* record or columnar format

<u>*DAY* Output Files</u>

root1.DAY	***DAY*** output file
root1.DMS	***D***AY ***m***e***s***sage file

Table 1.3
Matrix of Input and Output Files and Programs

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

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

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

Scope and Organization of this Manual

This report serves as both reference and users manuals for WRAP features providing capabilities for simulation of flood control reservoir system operations, simulation of pulse flow environmental instream flow requirements, and options related to adoption of daily computational time steps that include monthly-to-daily disaggregation of flows and demand targets and flow forecasting and routing. The term daily is used throughout this manual for brevity, realizing that other sub-monthly time intervals may be adopted as well. A daily computational time step is expected to be used in most sub-monthly applications of WRAP.

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

A daily time step can be useful in modeling all aspects of water management including water supply and hydropower. However, the daily modeling capabilities are particularly relevant for simulating flood control operations and environmental instream flow requirements. Simulation of flood control reservoir operations is discussed in Chapter 5. Features for modeling and analysis of pulse flow environmental instream flow requirements are described in Chapter 8. Chapter 6 combines a general summary review of WRAP frequency analysis methods with a more focused presentation of flood frequency analysis methods.

Chapter 7 consists of a set of five examples that illustrate the modeling capabilities presented in the preceding Chapters 2, 3, 5, and 6. The example presented in the *Fundamentals Manual* is expanded in Chapter 7 to include converting the monthly model to a daily time step, adding reservoir flood control operations, and environmental flow modeling and analysis capabilities. Chapter 4 includes a routing parameter calibration example. Chapter 8 includes examples of modeling and analysis of pulse flow environmental instream flow requirements.

WRAP modeling capabilities are applicable to systems covering the full range of complexity from studying operation of a single reservoir to investigations of river basins with hundreds of water users and hundreds of reservoirs operated for an array of purposes. The *Fundamentals Manual* example which is expanded in Chapter 7 of this *Daily Manual* was adapted from the TCEQ WAM System dataset for the Brazos River Basin, which has about 700 reservoirs and 3,800 control points. The simplified example designed for illustrative purposes is reduced to a system of six reservoirs, 11 control points, and hypothetical water management and use requirements. However, the modeling capabilities documented by this *Daily Manual* have also been applied using the complete TCEQ WAM System Brazos River Basin dataset (Wurbs, Hoffpauir, and Schnier 2012).

A list of references cited in this manual is provided on pages 211-212.

Appendices A, B, and C provide instructions for preparing input records for programs *SIMD*, *DAY*, and *TABLES*, respectively. Appendices A and C include those *SIMD* and *TABLES* input records that are not already covered in the basic *Users Manual*.

In summary, this *Daily Manual* supplements the *Reference* and *Users Manuals* to cover the additional capabilities incorporated in *SIMD* that are not included in *SIM* and the corresponding features of *TABLES*. The WRAP modeling system documented by the *Reference* and *Users Manuals* uses a monthly time step. The daily modeling system documented by this *Daily Manual* allows a more detailed simulation with a smaller computational time step, typically a daily interval.

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

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

- *Chapter 4*. The WRAP program *DAY* provides calibration techniques for determining values for the flow routing requires parameters that are covered in Chapter 4.

- *Chapter 5*. The daily model provides the framework required to model flood control. Additional new *SIMD* simulation features model any number of flood control reservoirs operated either individually or as multiple-reservoir systems to reduce flooding at downstream control points. Operating rules are based on emptying flood control pools expeditiously while assuring that releases do not contribute to flows exceeding specified flood flow limits at downstream control points during a specified future forecast period.

- *Chapter 6*. A general summary of frequency analysis methods is presented in Chapter 6. Flood frequency analysis techniques provided by *TABLES* and *HEC-SSF* are also introduced. Frequency analyses of annual peak naturalized flow, regulated flow, and reservoir storage are performed based on the log-Pearson type III probability distribution.

- *Chapter 7*. The five examples in Chapter 7 build upon and expand the *Fundamentals Manual* example to illustrate the modeling capabilities presented in the preceding chapters along with basic environmental instream flow modeling capabilities covered in the *Reference* and *Users Manuals*. The Chapter 7 examples are further expanded in Chapter 8 to include modeling and analysis of pulse flow environmental instream flow requirements.

- *Chapter 8*. The environmental instream flow modeling and analysis features of the monthly *SIM* and *TABLES* are also applicable in the daily *SIMD* and *TABLES*. The much more detailed daily modeling system significantly increases the accuracy and validity of the environmental instream flow analyses. Additionally, the daily computational time step also allows modeling pulse flow environmental instream flow requirements using new target setting features that have been added to *SIMD* which are documented by Chapter 8.

- *Appendices A, B, and C*. The *Users Manual* describes *SIM* and *TABLES* input records. The additional *SIMD* and *TABLES* input records required to implement the daily modeling capabilities are described in Appendices A and C of this supplemental *Daily Manual*. The input records for the program *DAY* are described in Appendix B.

CHAPTER 2
DAILY MODELING SYSTEM

The WRAP daily modeling system was developed by expanding the programs *SIM* and *TABLES* to incorporate additional features and creating the new program *DAY*. The simulation model *SIMD* (*D* for daily) consists of the monthly *SIM* in its entirety along with the major additional features described in this manual. Options are provided in the post-simulation program *TABLES* for developing frequency and reliability relationships using either sub-monthly time step simulation results or aggregated monthly results. Program *DAY* contains routines for calibration of routing parameters for use in *SIMD* and the same flow disaggregation methods as *SIMD* for developing sequences of naturalized flows or flow patterns for input to *SIMD*.

The WRAP simulation model *SIMD* allows each of the 12 months of the year to be divided into an integer number of time steps. The maximum limit is currently set at 32 time steps per month. The term *daily* is used in this manual synonymously with the term *sub-monthly* since the day is the sub-monthly interval expected to be adopted most often. With the default daily time step, each month is subdivided into 31, 30, 29 (leap year February), or 28 days.

A conventional monthly time step simulation may be performed with *SIMD* with the same input datasets used with *SIM*. Supplemental input is added to apply the *SIMD* sub-monthly features. Naturalized river flows generate most of the daily or sub-monthly variability in the simulation. Flow forecasting and routing are incorporated in the computations to simulate lag and attenuation effects. All simulation result variables are computed by *SIMD* for each time step, but the sub-monthly amounts may be summed to monthly values. *TABLES* organizes *SIMD* simulation results and develops frequency and reliability tables using either daily or other sub-monthly computational time step *SIMD* results or aggregated monthly amounts. *DAY* is a pre-simulation utility program providing options for developing certain *SIMD* input data.

The sub-monthly (daily) features of the *WRAP-SIMD* simulation model include:

- routines for setting the number of sub-monthly computational time steps contained in each month and subdividing monthly quantities to the smaller time steps
- alternative options for varying diversion, hydropower, and instream flow targets over the sub-monthly time steps within each month
- option for reading an input file of sub-monthly naturalized flows
- alternative methods for disaggregating naturalized monthly flows to daily that range in complexity from a linear interpolation routine that requires no additional input data to methodologies that reproduce the daily variability exhibited by sequences of daily flows or flow patterns provided as model input
- determination of current day available stream flow for *WR* record water rights based on a forecast simulation over a future forecast period and reverse routing
- forecasting of remaining channel capacity for *FF*/*FR* record flood control operations
- methods for routing of stream flow adjustments
- aggregation of sub-monthly simulation results to monthly values and recording of simulation results at sub-monthly and/or monthly time steps

Modeling with Daily Versus Monthly Time Steps

Most reservoir/river system models use either a monthly or daily time step (Wurbs 2005). The effects of computational time step choice on simulation results vary with different modeling applications. Flow averaging over longer time intervals tends to over-estimate capabilities for meeting requirements for water supply, environmental instream flow, hydroelectric power, and flood control. Accurate modeling of flood control operations is particularly difficult with a time step much greater than a day due to the extreme fluctuations in flow rates over short time spans associated with flood events. The effects of adopting a time interval of finite length on model results related to capabilities for meeting water supply, hydropower, and environmental instream flow requirements depend largely on the reservoir storage capacities available for mitigating flow fluctuations. Choice of time interval tends to affect reliability estimates for run-of-river diversion and instream flow targets much more than if there is reservoir storage to mitigate flow fluctuations. However, simulation results for systems with large reservoirs may also be affected by the choice of time interval.

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

The following considerations are addressed in this section.

- Flow rates that vary continuously over time in the real world are modeled as volumes occurring during discrete time intervals. Thus, comparisons of stream flow rates with water management/use targets in the model are based on total volumes during finite time intervals rather than instantaneous rates at points in time.

- In a monthly time step model, the effects of reservoir releases and water management/regulation/use actions on stream flows at downstream locations are assumed to propagate through the system within the same month, precluding flow forecasting and routing computations. However, flow forecasting and routing are important in typical modeling applications based on a daily time step.

Instantaneous Flow Rate versus Mean Flow Rate for a Time Interval

A hydrograph of instantaneous stream flow rates at a location on a river over a six-month period is plotted in Figure 2.1. A constant target flow rate is also plotted. This target could be either a minimum instream flow requirement or a diversion demand. The flow rate above which flood damages begin to occur is also shown. The river flow, instream flow or diversion target, and maximum non-damaging flood level are instantaneous flow rates that could be expressed in m^3/s, ft^3/s, or any other units of discharge. The flow volume during any specified time interval is represented by the area under the flow plot. For example, the total river flow during the six-month period may be computed as the area under the stream flow hydrograph during January through June. Likewise, the total volume of the target during the six-month period is represented by the rectangular area under the plot of the instantaneous target discharge rate extending from January through June. A volume occurring during a specified time interval may be expressed as a mean flow rate during the interval in units such as m^3/s, thousand m^3/day, thousand $m^3/month$, million $m^3/year$, ft^3/s, acre-feet/day, acre-feet/month, or acre-feet/year.

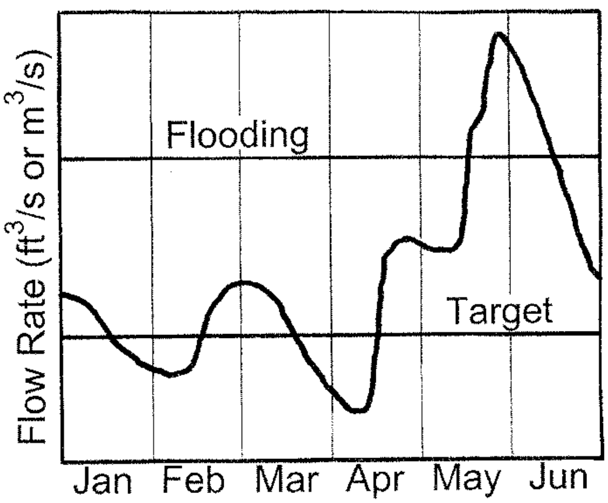

Figure 2.1 Stream Flow Hydrograph and Water Management Targets

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

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

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

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

Flow Forecasting and Flow Routing

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

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

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

1. The amount of water available to that water right is determined as the minimum of available stream flows at the control point of the water right and at control points located downstream. In the *SIMD* simulation of flood control operations, the amount of channel flood flow capacity below maximum allowable (non-damaging) limits is determined at all pertinent control points.

2. The water supply diversion target, hydroelectric power generation target, minimum instream flow limit, or non-damaging flood flow limit is set.

3. Decisions regarding reservoir storage and releases, water supply diversions, and other water management/use actions are made; net evaporation volumes are determined; and water balance accounting computations are performed.

4. The stream flow array used to determine water availability and remaining flood control channel capacity at all downstream control points is adjusted for the effects of the water management actions.

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

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

<u>Computer Programs, Data Files, and Input Records</u>

The programs *DAY*, *SIMD*, and *TABLES* contain features associated with modeling with a daily or other sub-monthly time step. Input and output files are listed in Table 1.2 of Chapter 1. Input records are described in Appendices A, B, and C.

<u>WRAP-DAY</u>

DAY is a utility program for developing *SIMD* daily stream flow input data. Monthly naturalized flows and net evaporation depths, common to both *SIM* and *SIMD*, can be developed using the hydrology program *HYD*. Program *DAY* performs the following tasks in developing additional hydrology data for a daily simulation.

- disaggregation of monthly flows to sub-monthly time steps
- calibration of river routing parameters as described in Chapter 4
- conversion of flow data in various formats to the standard format of *DF* records in a DCF file

Flows or flow patterns and river routing parameters developed by *DAY* are provided as input to *SIMD*. *DAY* is designed as an optional aid in developing *SIMD* input data but is not actually required for applying *SIMD*. The flow disaggregation routines in *DAY* are also incorporated in *SIMD*. Routing parameters may be developed by other means for input to *SIMD*.

DAY has a main input file with the filename extension DIN that contains records controlling each flow disaggregation or calibration task. The input records are described in Appendix B. Program *DAY* reads monthly and daily flows from the same FLO and DCF input files read by *SIMD*. Results of the *DAY* computations are written to an output file with the filename extension DAY. The *WRAP-DAY* message file has the filename extension DMS.

<u>WRAP-SIMD</u>

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

- *JT and JU* records control time step, output, and forecasting aspects of the simulation.
- *TI* record specifies sub-monthly time intervals other than the default daily.
- *W2*, *C2*, *C3*, *G2*, and *R2* records control selection of sub-monthly interval output.
- *DW* and *SC* records specify target and forecast data related to individual water rights.
- *DO*, *PF*, *PO*, and *SC* records specify target setting features for individual water rights.
- *RT*, *DC*, *DE*, and *DH* records provide routing and disaggregation specifications and data.
- *DF* record provides sub-monthly flows or flow patterns.
- *FR*, *FF*, *FV*, and *FQ* records implement flood control features described in Chapter 5.

The *RT*, *DC*, *DE*, *DH*, and *DF* records and optionally *DW/SC* and *DO/SC* records are stored in a separate file with the filename extension DCF. The other records are added to the DAT file. Descriptions of these *SIMD* input records are provided in Appendix A.

SIMD writes simulation results at sub-monthly time intervals to a file with the filename extension SUB. The sub-monthly interval simulation results are aggregated by month within *SIMD* to create an output file with the filename extension OUT. The flood frequency analysis file with the filename extension AFF contains annual series of maximum naturalized flow, regulated flow, and reservoir storage. *SIMD* optionally writes routing factor arrays, forecast availability periods, disaggregation parameters, and other optional *SIMD* specific information to the SMM file. The four output files created by *SIMD* are optional; either or all may be used.

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

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

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

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

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

Table 2.1
Organization of the *SIMD* SUB Output File

First Six Records of *SIMD* SUB Output File

WRAP-SIMD (September 2011 Version) Output File
TITLE1
TITLE2
TITLE3
BEGYR BEGMON ENDYR ENDMON DAYS NCPO2 NWROUT2 NREOUT2
NTI NDAY(1,…,12)

Definition of Variables on Fifth Record

BEGYR − first year in output file
BEGMON – first month in output file
ENDYR − last year in output file
ENDMON − last month in output file
DAYS – number of days (time steps) in output file
NCPO2 − number of control points in output file
NWROUT2 − number of water rights in output file
NREOUT2 − number of reservoirs in output file

Definition of Variables on Sixth Record

NTI – parameter (*JT* record) indicating calendar or user defined intervals in each month
NDAY(1,…,12) – number of time intervals used per month

Block of Records Repeated for Each Period (Month)

water rights output records (number of records = *NWROUT2*)
control point output records (number of records = *NCPO2*)
reservoir/hydropower output records (number of records = *NREOUT2*)

Total Number of Records in SUB File for Calendar Day Simulations

number of records = 6 + (12×*NYRS*×∑*NDAY*+(Number of Leap Years)) ×
(*NWROUT2* + *NCPO2* + *NREOUT2*)

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

number of records = 6 + (12×*NYRS*×∑*NDAY*)×(*NWROUT2* + *NCPO2* + *NREOUT2*)

Program TABLES

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

TABLES input records are described in Appendix C. The following *TABLES* type 6 records are designed for organizing the *SIMD* SUB file simulation results.

- Sub-monthly time series records such as *6NAT*, *6REG*, *6UNA*, *6STO*, *6DIV*, etc., described in Appendix C are analogous to the monthly time series records *2NAT*, *2REG*, *2UNA*, *2STO*, *2DIV*, etc., which are described in the basic *Users Manual*.
- *6REL* and *6RET* reliability records are analogous to *2REL* and *2RET* records.
- *6FRE* and *6FRQ* frequency records are analogous to *2FRE* and *2FRQ* records.
- The *6RES* reservoir storage reliability and drawdown frequency record described in Appendix C is analogous to the *2RES* record described in the *Users Manual*.

The *SIMD* and *TABLES* reservoir flood control features covered in Chapter 5 use daily time steps. The flood frequency analysis computations activated by the *TABLES 7FFA* record using peak annual series of storage, naturalized flow, and regulated flow from the *SIMD* AFF file are described in Chapter 5.

Monthly-to-Daily Disaggregation

The sub-monthly *SIMD* simulation model is an extension of the monthly *SIM*. The computational algorithms of both *SIM* and *SIMD* are organized based on stepping through the hydrologic period-of-analysis month-by-month. *SIMD* allows each of the 12 months of the year to be divided into any integer number of intervals up to 32, thus increasing the number of computational time steps. The default sub-monthly time interval is one day, with each month except February having either 31 or 30 days. February has 28 days except for leap years with 29 days. Alternatively, each of the 12 months may be subdivided into any other integer number of intervals between 1 and 32 by use of the time interval *TI* record. For the sake of brevity, the terms *daily* and *sub-monthly* are used synonymously throughout this manual.

The simulation computations are performed for each time step of the hydrologic period-of-analysis. Selected *SIMD* sub-monthly simulation results may be written to the SUB output file for each time step as specified by output control parameters included on the *JT*, *W2*, *C2*, *G2*, and *R2* records in the DAT input file. *SIMD* also totals the sub-monthly simulation results to aggregated monthly amounts which are recorded in the OUT file. The routines in *TABLES* handle the sub-monthly time step simulation results in a *SIMD* SUB output file or the monthly results in a *SIM* or *SIMD* OUT file in the same manner.

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

- <u>*Naturalized flows*</u> may be provided directly as input data on *DF* records at a daily or other sub-monthly interval. Alternatively, sub-monthly naturalized flows may be computed within the model by disaggregating monthly flows using the alternative options described later in this chapter. Monthly flow changes from *FA* records in a FAD file are added to the naturalized flows prior to the disaggregation.

- *Instream flow targets* may be uniformly distributed over the sub-monthly time intervals. Alternatively, other options described later in this chapter may be adopted.
- *Diversion and hydropower targets* may be uniformly distributed over the sub-monthly time intervals. Alternatively, options described later allow targets to vary non-uniformly across a month depending upon daily water availability and various other considerations.
- *Net evaporation-precipitation depths* from the *EV* records in an EVA or DSS file and *Constant inflows* from *CI* records in a DAT file are uniformly distributed. The monthly quantities are simply divided by the number of days in the month.

Disaggregation of Naturalized Stream Flows

The Texas WAM System contains datasets of monthly naturalized flows. Disaggregation options are adopted when applying daily time steps. In applying WRAP outside of Texas, the optimal daily time step modeling strategy will also often be to develop monthly naturalized flow sequences for use in combination with the *SIMD* disaggregation options. Selecting and applying the disaggregation options is a somewhat subjective process of making optimal use of available monthly and daily flow data. Historical gaged daily flow records and daily data related to past water control and use required to convert gaged flows to naturalized or unregulated flows may be limited in availability. Lag and attenuation effects complicate the process of naturalizing gaged flows and transferring them to ungaged sites. Converting gaged daily flows to naturalized daily flows at pertinent locations is difficult for extensively developed river basins.

SIMD reads monthly flow volumes from *IN* records or DSS records for primary control points and distributes the flows to secondary control points using DIS file parameters just like *SIM*. These monthly flows are then disaggregated to daily amounts in *SIMD*. The alternative disaggregation methods all convert sequences of monthly naturalized flow volumes into daily flow volumes that preserve the monthly amounts.

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

Monthly-to-daily flow disaggregation computations are normally performed within *SIMD* as an integral part of a simulation. The naturalized flow disaggregation routines are also included in the utility program *DAY*. Sequences of river flows or flow patterns may be developed within program *DAY* and provided as input to *SIMD*.

Alternative Flow Disaggregation Methods

The alternative methods outlined in Table 2.2 for dividing monthly naturalized flow volumes between time steps within each month are activated by the *SIMD JU* and *DC* records. *JU* record field 2 sets a global default option. The default for this default setting option is to input daily flows on *DF* records without providing monthly flows. The global default defined by the *JU* record is applied to all control points unless overridden for individual control points by *DC* records. *DC* record field 3 is used to select a disaggregation method for an individual control point. Different methods may be adopted for different control points.

Table 2.2
Alternative Flow Disaggregation Methods

Daily Flows Input Without Monthly Flows

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

Monthly Flows Disaggregated without Input of Daily Flows

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

Monthly Flows Disaggregated Using Input Daily Flows or Flow Patterns

3. *Variability Adjustment Option* − The daily flow volumes computed with the linear interpolation routine (option 2 above) are adjusted to reflect the variability determined from daily flow sequences provided as input on daily flow *DF* records.
4. *Flow Pattern Option* − Daily flow amounts on *DF* records define a daily flow distribution pattern. Location adjustments are available with options 5 or 6 below.

Transferring Flow Patterns to Other Control Point Locations

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

Daily flow *DF* records may contain either sub-monthly naturalized flow volumes or amounts that are used to represent flow patterns. In the case of flow amounts defining patterns, only the relative amounts, not the actual amounts, are relevant. Each set of *DF* record flow sequences may be repeated for any number of control points and applied with different disaggregation options for different control points. The *DF* input records do not have to include data covering the entire hydrologic period-of-analysis. The flows on the *DF* records are repeated as necessary within the *SIMD* simulation to extend over the hydrologic period-of-analysis.

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

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

<u>*Automatic Upstream Option Assignment*</u>

The disaggregation methodologies for *DC* record field 3 options 1 through 6 are described below. If *DC* record field 3 is set to -1 through -6, the absolute value of field 3 sets the disaggregation option. Additionally all control points upstream of the control point listed in *DC* record field 2 will be assigned the same disaggregation option and parameters from *DC* record fields 3 to 12. Previously set values of the disaggregation option and parameters are overwritten as each *DC* record is read and processed from the DCF file. If disaggregation options -3, -4, -5, or -6 are selected, then upstream control points will automatically be assigned a *DF* record pattern. The method for automatic *DF* record pattern assignment is described in Appendix A. Chapter 7 presents examples using *DC* record field 3 option -4.

<u>*Option 1 − Uniform Distribution*</u>

The uniform distribution option consists of computing daily flow volumes by simply dividing the monthly flow volume by the number of sub-intervals in the month.

<u>*Option 2 − Linear Interpolation*</u>

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

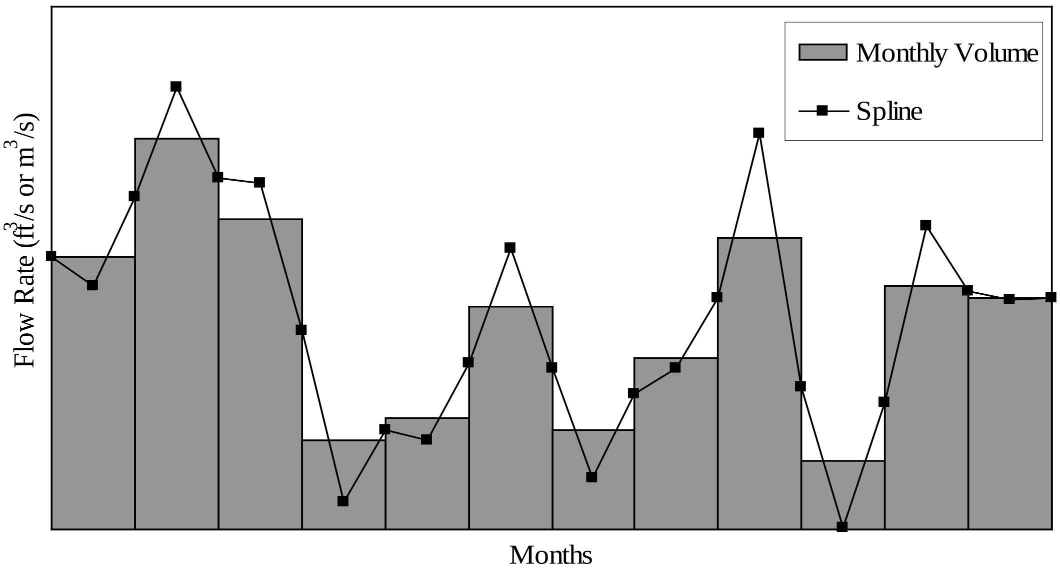

Figure 2.2 Linear Interpolation of Flow Volumes

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

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

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

Option 3 − Variability Adjustment

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

The variability adjustment option is designed for the common situation in which a complete dataset of monthly naturalized flows are combined with limited available sequences of daily flows. Daily flow sequences for one or a few years at one or a few locations may be used to establish patterns which are then used in disaggregating monthly flows to daily flows for the complete period-of-analysis at all control point locations. Patterns of variability derived from limited sequences of daily flows are repeated for multiple time periods and multiple locations.

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

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

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

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

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

VR is zero for each day that has zero flow on the *DF* record. Thus, the method reproduces the same percentage of days with zero flow for the daily flows (Q_D) adopted for the *SIMD* simulation as is found on the *DF* records.

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

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

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

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

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

Table 2.3
Combined Linear Interpolation with Variability Adjustment Strategy

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

Option 4 − Flow Pattern

A sequence of daily flow volumes defining a pattern of variability may be compiled external to *SIMD* and input on *DF* records. The *DF* record pattern flow sequences may cover the entire hydrologic period-of-analysis or some other period that may be much shorter. The flow pattern is repeated as necessary within the *SIMD* simulation or the *DAY* flow disaggregation computations to extend over the entire hydrologic period-of-analysis. The same flow pattern may be repeated for any number of control points.

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

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

An option 4 flow pattern defined by a set of *DF* records may be applied to multiple locations. A lag option activated by the parameter *LAG* entered on the *DC* record allows the daily flows to be shifted forward or backward in time for control points located upstream or downstream. The flows are simply translated a specified number of days to reflect timing. Options 5 and 6 described next change the relative magnitude of the flows to reflect watershed runoff differences between different control point locations.

The flow pattern method option 4 is based on entering a sequence of daily flows that are representative of flow variability. However, the pattern of daily flows derived from gaged flows at one particular location may not be representative of at various other sites with smaller or larger or otherwise different watersheds. Options 5 and 6 are methods for transforming and transferring the flow pattern represented by *DF* record flows to other locations.

Options 5 and 6 − Transferring a Daily Pattern to Other Locations

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

Daily flow variability patterns as well as total monthly volumes may vary with location. For example, daily flows at an ungaged upstream site with a relatively small watershed may exhibit greater variability than daily flows at a gaging station located downstream that has a much larger watershed. The flows provided on *DF* records are typically from a gaging station. The pattern of daily fluctuations derived from these flows may be applied to disaggregate monthly flows at other ungaged control point locations.

Options 5 and 6 listed in Table 2.2 are techniques for adjusting the daily flow pattern established with option 4 to reflect other locations in the river system with different watershed characteristics. Option 4 may be applied either with or without options 5 or 6 depending on whether the adjustment of flow variability patterns for watershed differences is considered significant and/or feasible. Options 5 and 6 are based on Equations 2.6 and 2.7, respectively. A related option activated by LAG on the *DC* record allows the entire period-of-analysis daily flow pattern sequence to be lagged backward or forward in time any number of days to account for the routing lag between locations. Details of these techniques are addressed in Appendices A and B.

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

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

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

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

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

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

Diversion, Hydropower, and Instream Flow Targets

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

1. A monthly target is determined at the beginning of each month in a *SIMD* daily simulation in the same manner as a *SIM* or *SIMD* monthly simulation. *UC* record use coefficients are combined with an annual target from a water right *WR* or instream flow *IF* record. The target may be adjusted further by target options *TO*, supplemental options *SO*, cumulative volume *CV*, flow switch *FS*, drought index *DI*, and other supporting records as described in the *Reference* and *Users Manuals*.

2. The monthly target set in step 1 above is distributed over the days of the month using one of the following two alternative approaches as specified by parameters on *JU* and *DW* records.

    - uniform distribution
    - specified number of days (*ND*) option with or without shortage recovery (*SHORT*) option

3. The daily target for a *WR* or *IF* record water right optionally may be set or adjusted using options specified on *DW* and *DO* records that are analogous to the *TO*, *SO*,

BU, *CV*, *FS*, and *DI* record monthly target setting options noted in step 1 above. Pulse flow *PF* and *PO* records are considered on a daily basis only for target building and are further detailed in Chapter 8 of this *Daily Manual*.

For most modeling applications, daily targets will be set for most water rights (*WR* and *IF* records) by combining options from the first two sets of options listed above. However, the third set of options is also available as needed.

<u>Uniform Distribution and ND/SHORT Options</u>

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

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

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

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

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

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

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

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

<u>*Sequential Step-by-Step Monthly and Daily Target-Building Process*</u>

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

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

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

<u>Steps in Building a Monthly Target on the First Day of Each Month</u>

1. Annual targets entered in *WR* or *IF* record field 3 are distributed into monthly amounts using multipliers developed from *UC* records. *UC* records are not required if the target is constant over the year. Alternatively, the *XMONTH* option on the *WR* or *IF* record sets the value in *WR/IF* field 3 as the target in each month. The *DW* record *XDAY* option moves consideration of the *WR* and *IF* record target to step 14 of the target building process.

2. The *BU* record activates the backup option as the second step in the target building routine or alternatively as step 10. The shortages incurred by one or more other specified rights are added to the monthly target of the current right determined in step 1 above. *DO* record field

2 moves consideration of the *BU* record to step 15 or step 20 of the target building process. If the *BU* record is considered in step 2 or 10, the *BU* record will always develop a target equal to the total monthly shortage during the prior month for the specified water right(s).

3. The optional drought index defined by a set of *DI/IS/IP* records modifies any target set in steps 1 and 2 above as a function of reservoir storage. A negative *DINDEX* entered on the *WR* or *IF* record switches application of the drought index until step 6. *DO* record field 4 moves consideration of the drought index to step 18 of the target building process.

4. One or multiple *TO* records may be used to continue to build a diversion or instream flow target as a function of a variable selected by *TOTARGET* in *TO* record field 2. The *TO* record based target is combined with the target determined in the preceding steps by either taking the maximum or minimum or by adding. Lower and upper limits may be placed on the targets. The first two of the three different options for applying limits are applied here. The third variation is activated by *TOTARGET*=10 with the limits applied later as step 7. A continuation option allows the target building to continue using the next *TO* record.
In a daily simulation, step 4 *TOTARGET* options −1, −2, −3 and −5 involve computing the target as a function of total flow in the previous month. *TOTARGET* option −4 refers to the storage volume at the end of the previous month. *DO* record field 3 moves consideration of the *TOTARGET* options to step 16 of the target building process.

5. A time series of monthly targets for each month of the hydrologic period-of-analysis may be entered on *TS* records. The manner in which a *TS* record target is combined with the preceding intermediate (steps 1-4 above) target is specified by parameter *TSL*.

6. A drought index defined by a set of *DI*/*IS*/*IP* records modifies the target determined above as a function of the storage content of specified reservoirs. The drought index may be applied at this sixth step of the sequence or as step 3 above. *DO* record field 4 moves consideration of the drought index to step 18 of the target building process.

7. *TOTARGET*=10 in *TO* record field 2 results in *TO* record fields 5 and 6 limits being applied at this point in the computations. In a daily simulation, when applying the *TOTARGET=10* option in step 7, the limit on either the target or quantity setting target is applied to the monthly target value prior to distribution to daily target amounts. *DO* record field 3 moves consideration of the *TOTARGET*=10 option to step 17 of the target building process.

8. A flow switch *FS* or cumulative volume *CV* record may modify the target based on the total volume of a selected variable accumulated during a specified preceding number of months and/or current month. With a *FS* record, one of two alternative multipliers are applied to the target depending on whether the volume of the defined variable falls within a specified range. A *CV* record provides several options for creating or modifying a target. Unlike step 9 below, step 8 applies the any number of *CV* and *FS* records entered with the current *WR* or *IF* record water right along with the other records. *DO* record field 5 moves consideration of *FS* and *CV* record options from step 8 or 9 to step 19 or 20 of the target building process.

9. The *FS* or *CV* record for step 9 is entered with another water right and referenced by an integer identifier in *WR* field 10 or *IF* field 9 of the current right. The target volume or switch multiplier factor provided for the current right by the *FS* or *CV* record may reflect the preceding steps 1-8 for the water right record group in which the *FS* or *CV* record is located.

10. The backup option activated by the *BU* record may be applied as either step 2 or step 10. The backup right's own target is first determined as outlined above, and then shortages incurred by one or more specified other rights are added. *DO* record field 2 moves consideration of the *BU* record to step 15 or step 20 of the target building process.

11. The target is adjusted as necessary to prevent exceeding the optional monthly or annual reservoir withdrawal limits entered in *SO* record fields 7 and 8. Steps 11 and 12 occur at the end of either the daily or monthly target building process. In a daily simulation, the steps 11 and 12 application of *SO* record limits occurs at the end after step 22.

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

Distributing the Monthly Target to the Days of the Month

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

Steps in Building or Adjusting the Daily Target

14. *DW* record parameter *XDAY* moves consideration of *WR* or *IF* record targets to step 14 of the target building process. The *AMT* value in *WR* or *IF* record field 3 is directly used as daily target amounts. If the *JU* or *DW* record *ND* option is not activated (*ND* = 0), *XDAY* will result in the *WR* or *IF* field 3 target being used as the daily target in every day of the month. If the *JU* or *DW* record parameter *ND* is set to a positive value, it will be considered in step 13 for any monthly target built in steps 1 through 12, as well as considering any *WR* or *IF* field 3 target as the daily target in the first *ND* days of the month in step 14.

15. *DO* record field 2 moves consideration of the backup *BU* record shortages to step 15. *BU* record shortages considered here use the current day shortage of the specified water right(s) for each day of the month that a shortage is generated by the specified water right(s).

16. *DO* record field 3 moves consideration of *TO* record options from step 4 to step 16. *TO* record options will be applied in every day of the month unless the *ND* option is activated. If the *ND* option is used, the *TO* records will only be applied in the first *ND* days of the month. The preceding-period *TO* record options (*TOTARGET* = −1, −2, −3, −4 or −5) considered here are always based on flow or storage volume in the preceding day.

17. *DO* record field 3 moves the *TO* record options of step 7 to step 17. The options are applied in every day of the month in step 17 unless the *ND* option is activated. If the *ND* option is used, the *TOTARGET=10* option will only be applied in the first *ND* days of the month.

18. *DO* record field 4 moves consideration of drought index defined by a set of *DI*, *IS*, *IP*, and *IM* records to step 18.

19 and 20. *DO* record field 5 moves activation of the flow switch *FS* and cumulative volume *CV* record options from steps 8 and 9 to steps 19 and 20. Pulse flow *PF* and pulse flow options *PO* records are considered in *SIMD* only. *DO* records are not required to activate *PF/PO* records in step 19 of the target building process.

21. *DO* record field 2 moves consideration of the *BU* record shortages to step 21. *BU* record shortages considered here will always use the current day shortage of the specified water right(s) for each day of the month that a shortage is generated by the specified water right(s).

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

Limitations on Withdrawals from Reservoir Storage

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

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

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

<u>Overview Summary of Daily *SIMD* Simulation Features</u>

Monthly datasets from the TCEQ Water Availability Modeling (WAM) System or other monthly datasets may be converted to a daily model, resulting in both daily and monthly versions of the dataset for a particular river basin. Alternatively, a daily WRAP model may be developed directly without an accompanying monthly version. Developing a *SIMD* daily simulation model involves various choices in combining a variety of user-selected options associated with the modeling capabilities outlined in Table 2.4 and described in Chapters 2, 3, and 4. The features listed in Table 2.4 are related to each other in various ways. Choices of options to adopt for routing parameter calibration, flow disaggregation, target setting, forecasting, routing, and next-day placement of routed flows are interconnected.

Table 2.4
Outline of Daily Simulation Features

<u>Calibration of Routing Parameters in DAY (Chapter 4)</u>

- iterative simulation
- optimization using genetic algorithm
- conventional Muskingum calibration

<u>Disaggregation of Quantities from Monthly to Daily in SIMD (Chapter 2)</u>

➢ Naturalized Stream Flows

Daily flows provided as input

Disaggregation of monthly flows to daily flows

- uniform distribution
- linear spline interpolation
- linear interpolation with variability adjustment
- reproduction of daily flow patterns

➢ Diversion, Hydropower, and Instream Flow Targets

- uniform distribution of monthly targets to daily
- *ND*/*SHORT* options for varying targets during month
- target-building options

<u>Flow Routing and Flow Forecasting (Chapter 3)</u>

➢ Forward and Reverse Routing of Flow Changes

- lag and attenuation method
- Muskingum adaptation

➢ Forecasting Supply Availability and Flood Release Capacity

<u>Other Stream Flow Accounting Features of the SIMD Simulation (Chapter 3)</u>

➢ Next-Day Placement of Routed Flow Changes

- at the beginning of the next-day simulation
- within the water rights priority sequence

➢ Negative Incremental Flow Options

➢ Routing Adjustments to Maintain Volume Balance

Disaggregation and Aggregation (Chapter 2)

Daily naturalized flows may be provided directly in a *SIMD* input DCF file without monthly flows. Alternatively, daily flows may be developed by disaggregation of monthly naturalized flows using optional methods incorporated within *SIMD* and *DAY*. The choice of disaggregation method depends largely on the availability of daily flow data representative of natural conditions. WRAP provides flexible options to design flow disaggregation strategies for a broad range of situations ranging from having extensive daily flow data available to having no daily flow data. Modeling choices are motivated by making the best use of available flow data.

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

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

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

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

Flow Routing and Flow Forecasting (Chapter 3)

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

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

The lag and attenuation routing method was developed specifically for routing flow changes in *SIMD* and is the recommended option for most WRAP applications. An adaptation of the Muskingum method is also included in the modeling system. Program *DAY* provides a set of options, which are covered in Chapter 4, for calibration of parameters for either routing method.

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

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

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

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

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

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

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

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

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

The amount of stream flow available to a water right in Task 1 of Table 3.4 is the minimum *CPFLOW* array available flows in the current and forecast days at the control point of the water right and selected downstream control points. The reverse routing algorithm in *SIMD* delineates a matrix of downstream control points and future days that will be affected by a particular water right in the current day along with the effects of routing and channel losses on the flow changes resulting from the water right. The *CPFLOW* array available flows at these downstream control points reflect both the effects of senior rights and negative incremental flows. *JD* record *ADJINC* option 7 further restricts the downstream control points identified in the reverse routing to those at which senior rights are located. *ADJINC* option 7 is considered the most realistic approach for dealing with negative incremental flows in future days.

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

CHAPTER 3
FLOW ROUTING AND FORECASTING

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

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

Overview of the *SIMD* Water Accounting Procedures

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

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

Task 1: Availability Determination. – The amount of stream flow available to the water right is the minimum of the control point flow *CPFLOW* array available flows at the control point of the water right and at relevant control points located downstream, optionally adjusted for channel losses and/or routing. In simulating flood control operations, the amount of channel flood flow capacity below maximum allowable non-damaging limits is determined considering the control point of the flood control right and pertinent downstream control points.

Task 2: Target Set. – The water supply diversion target, hydroelectric power generation target, minimum instream flow limit, or non-damaging flood flow limit is set.

Task 3: Water Right Simulation. – For the water right being considered, decisions are made regarding reservoir storage and releases, water supply diversions, and other water management/use requirements, and appropriate actions are taken. Net evaporation volumes are determined. Water balance accounting computations are performed.

Task 4: Flow Adjustment. – The *CPFLOW* array used to determine water availability and remaining flood flow capacity in Task 1 is adjusted for the effects of the Task 3 water management and use actions associated with that particular water right.

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

Flow Forecasting and Routing

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

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

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

Routing Adjustments for Next Day Placement of Routed Flow Changes

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

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

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

Negative Incremental Flow Options

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

Negative Incremental Flows

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

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

Relevant Control Points Considered in the Determination of Available Flow

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

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

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

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

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

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

Options Activated by ADJINC in JD Record Field 8

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

As explained in Chapter 3 of the *Reference Manual*, options 4 and 6 involve a flow adjustment defined as the minimum amount of flow that must be added to the naturalized flow at a control point to alleviate all negative incremental naturalized. *SIMD* computes and applies negative incremental flow adjustments for a daily time step in the same manner as the monthly *SIM*. *SIMD* first determines daily naturalized flows at all control points and then computes daily negative incremental flow adjustments. *SIMD* applies daily negative incremental flow adjustments in the same manner that *SIM* applies monthly adjustments. In determining stream flow available for *WR* record water rights and filling *FR* record flood control reservoir storage at a particular control point, the adjustment amounts are added to control point flows at downstream control points but not at the control point of the water right. Since the negative incremental flows are defined by concurrent upstream and downstream flows in the same time step, options 4 and 6 are generally not applicable for a daily simulation that includes routing.

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

> Option 6 is same as option 4 except the downstream control points used in selecting the minimum flow from the *CPFLOW* array are limited to the sites of relevant senior rights.
>
> Option 7 is same as option 1 except the downstream control points used in selecting the minimum flow from the *CPFLOW* array are limited to the sites of relevant senior rights.
>
> Option 8 incorrectly ignores all downstream control points. The *CPFLOW* array flow at the control point of the water right is assumed to be the flow available to the water right.

Any of the eight *ADJINC* options can be adopted in *SIM* or *SIMD* monthly or daily simulations, except option 5 is not allowed in a daily simulation. Option 7 is recommended whenever routing is adopted, which is typically the case in a daily simulation. Option 1 restricts the flow amount available to water rights more than option 7 but is also applicable with routing. Option 6 is recommended if routing is not activated.

Option 7 is designed to be the standard *ADJINC* option to be adopted whenever routing and forecasting are employed, but can also be used in a monthly or daily simulation without routing and forecasting. The downstream control points identified in the reverse routing are further constrained to only those control points at which relevant senior rights are located. Flows at downstream control points not affected by senior rights have no effect on water availability for the junior right. Therefore, negative incremental flows at a downstream control point affect the amount of flow available to a particular water right only if senior rights also reduce the flows at the downstream control point. Option 7 is similar to option 5 but does not include all features of option 5. Option 7 is option 1 with the limitation to senior right control points added.

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

Routing Changes to Flow

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

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

Routing Flow Changes Associated with Water Rights

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

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

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

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

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

2. As each *WR* record water right is simulated, the *CPFLOW* array is adjusted for the effects of reservoir releases, refilling storage, diversions, and return flows. With *JU* record *WRMETH* option 1 and *WR* record *RFMETH* options 2 and 4, stream flow depletion and return flow changes, respectively, are aggregated and placed at the beginning of the next-day simulation. *WRMETH* option 2 and *RFMETH* options 2 and 4 apply routing separately for each individual right within the water rights priority sequence.

3. Flood control operations specified by the *FR* record are described in Chapter 5. Flow changes are associated with filling storage and subsequent releases from flood control pools. The parameter *FRMETH* on the *JU* record controls whether flood flow depletion and release changes affect the next-day flows at downstream control points at the beginning of the next-day simulation or within the priority loop computations.

Negative values may be generated in the *CPFLOW* array. *SIMD* sets these negatives to zero and adjusts the flow in the next time step to compensate. Thus, long-term volume balances are maintained though the volume balance may be violated in individual time steps.

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

The lag and attenuation method is recommended for most water availability modeling applications. The lag and attenuation method is (1) designed specifically for *WRAP-SIMD*, (2) easier to understand from the perspectives of both estimating values for the parameters and visualizing the routing computations in the simulation model, and (3) computationally stable with any control point spacing and reach travel times.

The adaptation of the Muskingum flood hydrograph routing method (1) is based on an accepted method that has been extensively applied in many models for many decades for routing flood hydrographs with a small time step, (2) may exhibit computational instabilities, particularly with control points separated by very short travel times, and (3) is more applicable for studies focused on simulating flood control operations than for low and normal flows.

WRAP Lag and *Attenuation Routing Method*

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

LAG − lag time in days for water right *WR* record flow changes
ATT − attenuation in days for water right *WR* record flow changes

LAGF − lag time in days for flood control reservoir *FR* record flow changes
ATTF − attenuation in days for flood control reservoir *FR* record flow changes

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

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

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

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

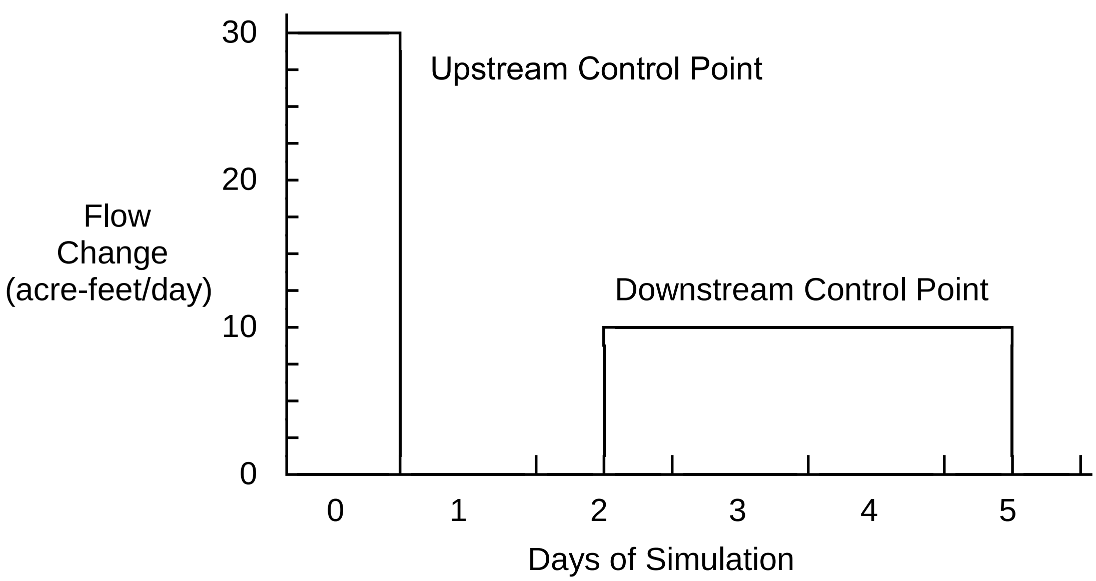

Figure 3.1 Routing for LAG of 4.5 Days and ATT of 3.0 Days

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

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

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

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

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

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

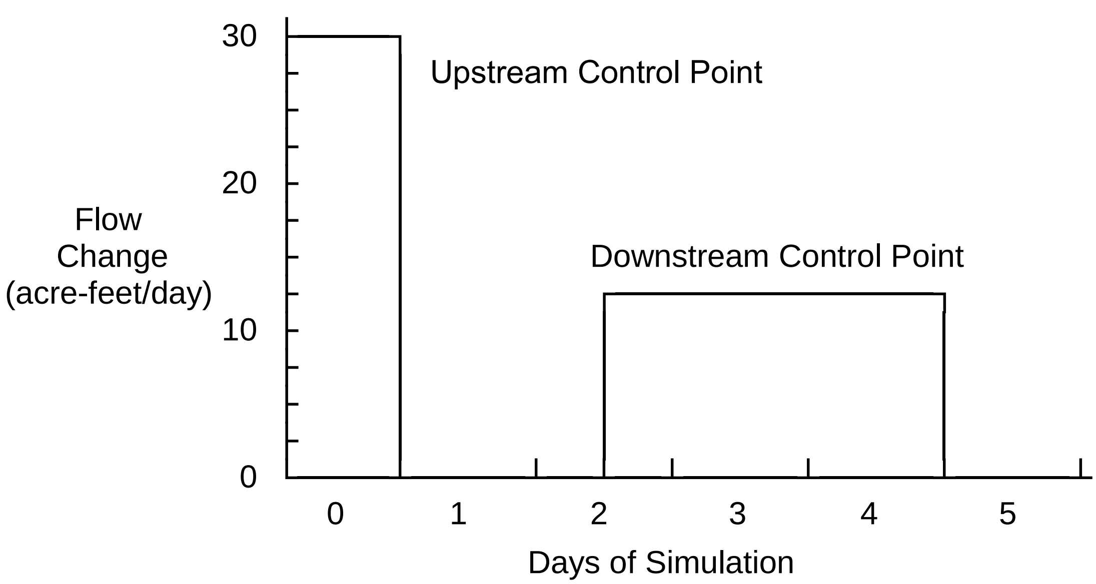

Figure 3.2 Routing for LAG of 4.0 Days and ATT of 2.5 Days

Muskingum Routing

The Muskingum method has been applied in many models over many years to routing flood hydrographs through river reaches (Wurbs and James 2002; McCuen 2005). The method dates back to a flood control study of the Muskingum River in Ohio by the Corps of Engineers in the 1930's. Muskingum routing has usually been applied for routing flood hydrographs. Given the discharge hydrograph at an upstream site, the corresponding hydrograph at a location further downstream is computed.

All hydrologic routing techniques are based on the continuity equation.

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

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

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

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

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

$$S = K\,(X\,I + (1.0 - X)\,O) \tag{3.3}$$

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

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

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

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

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

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

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

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

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

The parameter X is a weighting factor ranging from 0.0 to 1.0. In actual application, X must range between 0.0 and 0.5 to simulate flow attenuation. Natural river reaches have been found to often be characterized by a value for X of about 0.2. Without calibration studies, X=0.2 has sometimes been adopted for particular applications. The parameter K represents flow travel time and has been approximated by various methods for estimating travel time through a river reach (McCuen 2005). Values for X and K are normally established by calibration based on observed flows. Calibration routines for computing K and X are included in the program *DAY*.

Computational instabilities resulting in negative or otherwise unreasonable values for computed outflows are a problem with Muskingum routing if the river reach being modeled is too short or too long. McCuen (2005) and others have suggested the following rule-of-thumb limits on K and X to avoid these problems.

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

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

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

SIMD checks the input values of K and X and reports a warning message to the MSS file if the parameters violate the above criteria. K is the more critical parameter for routing accuracy. Parameter calibration is usually relatively insensitive to changes in X. A common practice is to assume most river reaches are modeled with an X of between 0.0 and 0.3. The value of X will decrease towards 0.0 as K increases to maintain numerical stability, and is physically related to increasing wave attenuation as travel time increases in the reach.

SIMD Adaptation of Muskingum Routing

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

The variables in Eqs. 3.9 and 3.10 are defined below from the perspective of routing in *SIMD* and are defined again later from the perspective of calibrating K and X in *DAY*.

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

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

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

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

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

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

Flow Forecasting

Forecasts of future stream flows may be applied in both water supply and flood control operations. As discussed in Chapter 5, reservoir operations for flood control are based on making no release today that contributes to downstream flooding today or during future days. In water supply operations, forecasting addresses the issue of water control and use decisions today affecting flows over the next several days from the perspective of the Task 1 stream flow availability determination outlined in Table 3.1. Since some lag time is required, perhaps several days, for flow changes to propagate downstream to the river system outlet, water supply diversions and return flows and multiple-purpose reservoir operations in the current time step affect regulated flows in subsequent time steps. The *SIMD* simulation algorithms protect senior water rights from the actions of junior rights in the current and preceding days.

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

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

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

Flow Forecast Period Parameters

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

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

The simulation forecast period (F_P) is the number of time steps into the future considered in determining water availability for a *WR* record right or remaining flood flow capacity for a *FR*/*FF* record right. This discussion refers to the F_P in terms of number of days though the time steps may also be sub-monthly intervals other than days. Forecasting is based on a F_P that may range in *SIMD* from 1 to the integer number of time steps in a year (365 days). A F_P of zero means no forecasting. Other time periods related to flow forecasting are defined below also in units of days, which again refers generically to any integer sub-monthly time step.

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

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

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

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

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

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

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

Forecast Simulation Followed by Actual Simulation in Each Time Step

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

Table 3.2
Forecast Simulation Followed by Actual Simulation

1. At the beginning of each time step (day) of the *SIMD* simulation, the daily time step simulation is performed for the simulation forecast period F_P for the sole purpose of forecasting future flow conditions. This forecast simulation starting with the current day uses forecast information developed from the forecast simulation performed for the previous actual day which is now outdated by one day and thus less accurate. The only results saved from the forecast simulation are:

    - array of downstream stream flow availability for each *WR* record water right
    - flood flow capacity array for each flood flow *FF* record control point

2. The actual daily time step simulation with flow availability array information developed in the forecast simulation described above is performed for the one day.

In each day of the multiple-day forecast simulation, water availability is determined considering that day and the latest but now outdated-by-one-day forecast for future days developed for the simulation previously performed for the preceding day. The only results saved are pertinent stream flow availability array and flood flow capacity availability array quantities. These stream flow quantities are approximate in that outdated forecasting is incorporated in their development. However, these flow quantities allow forecasting to be incorporated into the determination of flow available to each *WR* record water right and *FF* record flood flow capacities in the subsequent one-day actual simulation.

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

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

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

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

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

Reverse Channel Loss Computations and Reverse Routing in the Forecast Simulation

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

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

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

The term ($1.0 - F_{CL}$) is a delivery factor defined as the fraction of the flow at the upstream control point that reaches the next downstream control point. For control points in series, the water available *A* at the *Nth* control point below the stream flow depletion is adjusted as follows, where F_{CL1}, F_{CL2}, F_{CL3}, ..., F_{CLN} denote the channel loss coefficients for each of the *N* individual reaches between the control point at which the stream flow depletion *D* occurs and the control point at which the amount of available water *A* is being adjusted.

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

Routing and Forecast Reverse Routing

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

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

Routing and associated reverse routing are based on the two parameters LEL and TEL for a control point that delineate the transport of flow changes through the stream reach below the control point as illustrated in Figures 3.1 and 3.2. The other variables defined below are derived from the parameters LEL and TEL and are illustrated in the examples presented later.

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

trailing edge lag (TEL) − time in days as a real (decimal) number measured from the end of the current day to the point in time at which the upstream (trailing) edge of the routed flow change reaches the downstream end of the stream reach (downstream control point). TEL = LEL − ATT attenuation (ATT) − time difference between the trailing edge lag (TEL) and leading edge lag (LEL) measured as a real (decimal) number of days. ATT is the attenuation entered as RPARAMS(cp,2) or RPARAMS(cp,4) in routing *RT* record fields 5 and 7.

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

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

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

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

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

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

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

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

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

RFA(routing control point, downstream control point, day)

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

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

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

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

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

Routing and Reverse Routing Examples

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

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

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

Routing and Reverse Routing Example 1

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

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

Routing and Reverse Routing Example 2

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

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

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

Routing and Reverse Routing Example 3

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

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

The computations may result in extremely small quantities in the days at the leading and trailing edges of the block of flows. The *SIMD* routing and reverse routing includes a refinement consisting of setting a default lower limit of 1.0% of the total adjustment in any individual day. The 0.00463 at CP-4 in days 3 and 9 of the *RFA* of the example are set to zero with a corresponding increase from 0.05556 to 0.05633 in days 4 and 8. The *RFA* values at CP-5 in days 4, 5, 11, and 12 are likewise adjusted. The routed flow volumes are similarly adjusted for the 1.0% limit. Thus, the routed flows in any day are limited to not exceed 1.0% of 900 acre-feet, which is 9.0 acre-feet. Application of the 1.0% limit results in the modified Example 3 routed flow change and *RFA* array shown below.

Leading Edge Lag (LEL)		1.75 days	1.75 days	1.75 days	1.75 days
Trailing Edge Lag (TEL)		3.25 days	3.25 days	3.25 days	3.25 days
Attenuation (TEL−LEL)		1.5 days	1.5 days	1.5 days	1.5 days
Leading Edge Day (LED)		1	1	1	1
Trailing Edge Day (TED)		3	3	3	3
Spread (S)		3 days	3 days	3 days	3 days
Cumulative Leading Edge Day		1	2	3	4
Cumulative Trailing Edge Day		3	6	9	12
Cumulative Spread (CS)		3 days	5 days	7 days	9 days
Forward Routing					
	Flow Volume (acre-feet) at Control Point				
Day	CP-1	CP-2	CP-3	CP-4	CP-5
0	900				
1		150			
2		600	25		
3		150	200		
4			450	54.17	
5			200	212.5	11.79
6			25	366.7	69.4
7				212.5	211.1
8				54.17	315.3
9					211.1
10					69.4
11					11.79
12					
Routing Factor Array (RFA) Developed for Forecasting Reverse Routing					
	Flow Volume as a Fraction of Total at Control Point				
Day	CP-1	CP-2	CP-3	CP-4	CP-5
0	1.00000				
1		0.16667			
2		0.66667	0.02778		
3		0.16667	0.22222		
4			0.50000	0.06019	
5			0.22222	0.23611	0.01312
6			0.02778	0.40741	0.07716
7				0.23611	0.23456
8				0.06019	0.35033
9					0.23456
10					0.07716
11					0.01312
12					

Example 4 which Incorporates Channel Losses into Example 3

The channel loss factors (C_L) entered on *CP* records and corresponding delivery ratios are as follows for the four reaches of Example 4. The reverse channel loss computations are performed separately from the routing factor array *RFA* in *SIMD*. However, channel loss and routing effects are combined in the same factors in this illustrative example. The routing factors of Example 3 are multiplied by the cumulative delivery factors with the following results.

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

	Delivery Ratio x Routing Factor				
Day	CP-1	CP-2	CP-3	CP-4	CP-5
		DR = 0.80	DR = 0.68	DR = 0.51	DR = 0.459
0	1.00000				
1		0.13334			
2		0.53334	0.01889		
3		0.13334	0.15111		
4			0.34000	0.03070	
5			0.15111	0.12042	0.00602
6			0.01889	0.20778	0.03542
7				0.12042	0.10766
8				0.03070	0.16080
9					0.10766
10					0.03542
11					0.00602

The combined routing/loss factor array tabulated in the table above is interpreted as follows. A stream flow depletion in Day 0 at control point CP-1 of 1.0 acre-foot results in adjustments in the *CPFLOW* flow availability array in the amounts in acre-feet shown in the table above at control points CP-2, CP-3, CP-4, and CP-5 in Days 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11. Conversely, amounts in the *CPFLOW* array are divided by the fractions in the table above to determine water availability at CP-1 in Day 0. The volume of flow available at CP-1 in Day 0 is the minimum of the *CPFLOW* flow in Day 0 at CP-1 and each of the elements of the array of the *CPFLOW* flows divided by *RFA* elements for the 11 future days at CP-2, CP-3, CP-4, and CP-5. Thus, the volume of flow available at CP-1 in Day 0 is the minimum of the 21 numbers computed by dividing *CPFLOW* array available flows by the numbers in the table above.

The recommended *JD* record field 8 *ADJINC* option 6 is to limit the downstream control points considered in computing flow availability for a right to those control points at which senior water rights are located. In the example, senior rights may be located at all of the control points CP-2, CP-3, CP-4, and CP-5. However, if not, only the factors at the pertinent downstream control points are applied in determining the amount of stream flow available to the water right at control point CP-1.

CPFLOW array quantities are divided by the fractions in the combined channel loss and routing factor array table on the preceding page in the determination of flow availability. An alternative way of viewing the combined routing and loss factor array table is to take the reciprocals of the fractions in the above table to obtain the following table. The following version of the table is applied as follows to determine the amount of water available in Day 0 at control point CP-1. Volume amounts from the *CPFLOW* array are multiplied by the numbers in the array shown below and the minimum of the products is selected. The available flow is the minimum of the *CPFLOW* flow in Day 0 at CP-1 and these 20 products (21 flows).

	Multiplier Factors				
Day	CP-1	CP-2	CP-3	CP-4	CP-5
0	1.00000				
1		7.500			
2		1.875	52.937		
3		7.500	6.618		
4			2.941	32.577	
5			6.618	8.305	166.056
6			52.937	4.813	28.235
7				8.305	9.288
8				32.577	6.219
9					9.288
10					28.235
11					166.056

Forecasting in the Forecasting Simulation

The forecasted flows for the days covered by the maximum F_P are carried forward to the forecast simulation. The following example illustrates the incorporation of forecasting in the forecast simulation. The forecast period is 5 days. X in the table on the next page marks the day for which the simulation is performed and represents the *CPFLOW* flow for that day at that control point. Letters are used instead of numbers in the table to represented computed quantities. A, B, C, … , S, T are the quantities developed by combining the *CPFLOW* and *RFA* arrays that are used to determine flow availability for the particular water right being considered.

A, B, C, D, and E are the available flow quantities for each day of the 5-day forecast period in the final simulation when Day 1 is the current day determined considering all relevant control points. X, A, B, C, D, and E are each the minimum of *CPFLOW/RFA* quantities at multiple relevant control points identified in the RFA. The daily stream flow volume available to this water right in Day 1 is the lesser (minimum) of the *CPFLOW/RFA* ratios X, A, B, C, D, or E. The concept introduced here is that quantities B, C, D, and E are also used again in the forecast simulation when Day 2 is the current day.

Likewise, F, G, H, I, and J are the quantities for each day of the 5-day forecast period determined in the final simulation when Day 2 is the current day. These five quantities along with the Day 2 quantity are used to determine the flow availability for this water right in the Day 2 final simulation. Quantities G, H, I, and J are used again in the forecast simulation when Day 3 is the current day. In the 5-day forecast simulation for Day 3, quantities H, I, and J are used in estimating flow availability for Day 4, and I and J for the Day 5 estimate of available flow.

Example of Forecasting in the Forecasting Simulation

A forecast simulation covering the current day and 5 future days is followed by the actual final simulation for the current day for each of the four days shown. The X marks the current or future day for which the simulation is performed. The letters A through T represent the flow quantities developed by combining the *CPFLOW* and *RFA* arrays that are used to determine stream flow availability for the particular water right being considered. The forecast simulation uses the information available from the forecast for the preceding current day final simulation.

	Day	1	2	3	4	5	6	7	8	9
Current = day 1										
Forecast	1	X								
	2		XA							
	3			XB						
	4				XC					
	5					XD				
	6						XE			
Final Simulation	1	**X**	A	B	C	D	E			
Current = Day 2										
Forecast	2		X	B	C	D	E			
	3			XF	C	D	E			
	4				XG	D	E			
	5					XH	E			
	6						XI			
	7							XJ		
Final Simulation	2		**X**	F	G	H	I	J		
Current = Day 3										
Forecast	3			X	G	H	I	J		
	4				XK	H	I	J		
	5					XL	I	J		
	6						XM	J		
	7							XN		
	8								XO	
Final Simulation	3			**X**	K	L	M	N	O	
Current = Day 4										
Forecast	4				X	L	M	N	O	
	5					XP	M	N	O	
	6						XQ	N	O	
	7							XR	O	
	8								XS	
	9									XT
Final Simulation	4				**X**	P	Q	R	S	T

Applications of Flow Forecasting

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

1. Prevention of upstream junior rights from making depletions of stream flow in the current day which will otherwise be appropriated by downstream senior water rights during the forecast period.
2. Prevention of flood control reservoirs from making releases that contribute during the forecast period to flows at downstream locations exceeding specified allowable limits.

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

With *WRMETH* option 2 in *JU* record 6, stream flow depletions for each individual right are routed within the priority sequence, thus protecting senior rights from earlier actions of junior rights. However, forecasting is required to prevent *double-taking* of the same water where senior rights appropriate flows that have already been incorrectly appropriated by junior rights in previous days. Forecasting constrains junior rights along with protecting senior rights.

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

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

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

CHAPTER 4
CALIBRATION OF ROUTING PARAMETERS

Routing methods incorporated in *SIMD* are described in the preceding Chapter 3. Chapter 4 outlines capabilities provided by program *DAY* for determining routing parameters.

As discussed in Chapter 3, either the *SIMD* lag and attenuation method or the *SIMD* adaptation of the Muskingum method may be adopted for routing stream flow adjustments. The control points for which routing is to be applied must be selected and values must be estimated for the routing parameters. Different parameter values may be entered at a control point for flow changes associated with flood control *FR* record reservoir operations and flow changes for *WR* record rights. The routing parameters (*RPARAMS(cp,I)*, I=1,4) entered on the *RT* record in a *SIMD* input DCF file for an upstream control point consist of either:

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

Calibration routines in *DAY* are based on computing values for these routing parameters for reaches between control points based on the known naturalized flows or other given flows at the control points. The calibrated parameter values are then input to *SIMD* on *RT* records for use in propagating incremental changes in flows.

Program *DAY*

Program *DAY* is a set of routines for developing sub-monthly (daily) naturalized stream flow sequences and routing parameters for input to *SIMD*. *DAY* performs the following tasks.

- disaggregation of monthly naturalized flows to sub-monthly time steps and associated conversion of flow data in various formats to the standard format of *DF* records (JOBDIS record)
- calibration of parameters for routing flow changes (JOBRTG record)

The naturalized flow disaggregation routines in *DAY* are also incorporated in *SIMD* and are covered in the preceding Chapter 3. The present Chapter 4 covers the calibration of parameters for the lag and attenuation routing method and Muskingum routing method.

Instructions for developing input records for *DAY* are provided as Appendix B. *DAY* has a main input file with the filename extension DIN that contains records controlling each flow disaggregation or calibration task. *DAY* reads monthly and daily flows from the same FLO and DCF files read by *SIMD*. The *DAY* computation results output file and message file have the filename extensions DAY and DMS. Disaggregation and calibration jobs are activated by JOBDIS and JOBRTG records, respectively. The *DAY* input DIN file may contain any number of JOBDIS and JOBRTG records and their auxiliary supporting records. Computations are performed for each job in the order that the JOBDIS and JOBRTG records are read. Any number of parameter calibration jobs for different river reaches can be included in the same DIN file.

<u>General Considerations in Applying *DAY* Calibration Methods</u>

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

Changes in stream flows due to diversions, return flows, refilling reservoir storage, and reservoir releases are routed in *SIMD*. Thus, time series of incremental flow adjustments rather than total stream flow hydrographs are routed. However, data available for calibration studies typically consists of hydrographs of either gaged or naturalized stream flows. A *SIMD* simulation is based on naturalized daily river flows covering the entire hydrologic period-of-analysis. These daily flows at the control points defining the upstream and downstream ends of selected routing reaches are used by *DAY* to calibrate values for the routing parameters. The routing parameters are determined in *DAY* from these total flows and then applied in *SIMD* to rout adjustments or changes to the flows.

<u>*Routing Parameters*</u>

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

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

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

Parameters may be calibrated for selected reaches and transferred based on judgment to other reaches. Distance may serve as a surrogate for travel time in proportioning LAG, LAGF, MK, and MKF. Parameters values for selected reaches determined by calibration computations may be transferred to other reaches based on reach lengths. The Muskingum X may be assumed to be the same for multiple reaches, and K estimated based on proportioning travel time. Optimal reach lengths for Muskingum routing may be based on maintaining computational stability as defined by rule-of-thumb criteria such as Eqs. 3.13 and 3.14. Ideal reaches for the *DAY* calibration computations with either of the two routing methods are characterized as having acceptable lengths between gaging stations with little or no local or tributary inflows.

Gains or Losses of Flow in a River Reach

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

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

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

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

Program Day Calibration Features

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

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

The entire hydrologic period-of-analysis or any sub-portion thereof may be used to determine parameters for any user-selected control points. The user may define sequences of flows used in the *DAY* calibration computations by specifying the beginning and ending dates. For example, flood events may be selected for calibrating parameters for flood flows.

DAY also provides an option for specifying the range of flow to be used in the calibration. Flow range criteria are specified in terms of flow magnitude at the upstream control point.

Alternative Methods for Calibrating Routing Parameters

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

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

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

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

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

Iterative Simulation Option

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

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

comparative flow statistics:
- total volume
- percent of outflow hydrograph
- mean of flow
- standard deviation of flow
- flow percentiles

comparative difference statistics:
- mean of differences (computed flow − given flow)
- mean of absolute value of differences (computed − given)
- mean of positive differences (computed flow − given flow)
- mean of negative differences (computed flow − given flow)
- mean of differences (computed flow − given flow) squared
- largest positive difference (computed flow − given flow)
- largest negative difference (computed flow − given flow)

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

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

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

Optimization Option

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

Various types of search algorithms are available for this type of optimization problem. The HEC-Hydrologic Modeling System has two alternative gradient search algorithms used for calibrating the Muskingum K and X routing parameters as well as for calibrating parameters for various watershed precipitation-runoff models (Hydrologic Engineering Center 2008). *WRAP-DAY* uses an optimization strategy based on a genetic search algorithm. Genetic algorithms are evolutionary search techniques based on the mechanics of natural selection (Goldberg 1989; Mitchell 1998; Ranjithan 2005). A genetic algorithm is a type of directed stochastic optimization strategy. Genetic search algorithms may have an advantage over gradient search or deterministic optimization methods in that they may be less likely to converge on local rather than global optima. The genetic search algorithm incorporated in *DAY* for parameter calibration is described by Hoffpauir (2010).

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

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

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

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

$$F_1 = \sqrt{\frac{\sum_N \left(O_{known} - O_{computed}\right)^2}{N}} \qquad (4.2)$$

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

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

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

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

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

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

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

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

$$\text{Daily Lateral Flow Volume} = O_{known} - O_{computed} \tag{4.5}$$

$$\text{Total Lateral Flow Volume} = \sum_N \text{Daily Lateral Flow Volumes} \tag{4.6}$$

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

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

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

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

$$F_4 = (1.0 - W)\, F_1 + W\, F_3 \tag{4.8}$$

$$F_5 = (1.0 - W)\, F_2 + W\, F_3 \tag{4.9}$$

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

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

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

Reducing the Spread of Routed Flows

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

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

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

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

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

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

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

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

Direct Option for Calibration of Muskingum K and X

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

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

$$\frac{S_T - S_{T\text{-}1}}{\Delta t} = I_T - O_T \tag{4.14}$$

$$S_T = K\left[X\,I_T + (1.0 - X)\,O_T\right] \tag{4.15}$$

The variables are defined as follows.

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

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

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

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

$$\Delta S = \sum (I\ \Delta t\ -\ O\ \Delta t) \tag{4.16}$$

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

$$S_T = \sum \Delta S \tag{4.17}$$

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

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

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

Paired sequences of I_T and O_T are converted to paired sequences of $(XI_T+(1.0\text{-}X)(O_T))$ and S_T, with S_T computed with Eqs. 4.16 and 4.17. K is determined by applying linear least-squares regression (Chapter 2 Eqs. 2.13, 2.14, 2.15) to this paired series. K is the slope of the regression line. The computation of K is repeated for different values of X. The optimal values of X and K are those with the linear correlation coefficient (Eq. 2.17) being closest to 1.0.

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

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

The conceptual basis of the *DAY* computational methodology is the same as the graphical approach presented in hydrology textbooks such as McCuen (2005). Muskingum routing is based on the following premises, neither of which is strictly true but rather is approximately the case.

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

If these two premises were perfectly valid, a plot of S and $(XI+(1-X)O)$ would be a straight line for a series of known inflows and outflows for the river reach. The optimal value of X results in the typical looped relationship being as close to a straight line or the correlation coefficient being close to 1.0 as possible. The parameter K is the slope of the line.

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

Program *DAY* Routing Parameter Calibration Example

The *DAY* input and output files for this example are as follows:

DAYexam.DCF − The daily flow input file is from the preceding example.
The beginning of the DCF file is shown in Table 3.9.
DAYexam.DIN − The *DAY* input file is reproduced as Table 4.1.
DAYexam.DMS − The *DAY* message file is reproduced as Table 4.2.
DAYexam.DAY − The *DAY* output file is reproduced as Table 4.3.

The first job in the calibration example optimizes over the entire 1960-1969 daily period-of-record to obtain values for the lag-attenuation parameters *LAG* and *ATT* to be entered on the *RT* records for the river reaches below the Belton and Granger control points. There are 3,653 time steps (days) in the optimization computations. Optimizing over the entire period-of-record is intended to find routing parameters to be used for "normal flow" non-flooding conditions. The optimization uses objective function 5 which is a combination of matching the absolute error (objective function 2) and reproducing the lateral inflow volume (objective function 3). The absolute error objective function may be preferable for finding the routing coefficients for the entire period-of-record. Using a squared error objective function may be more useful for determining flood flow routing parameters. The calibration results in a *LAG* and *ATT* of 1.75 and 1.33 days, respectively, for the Belton to Cameron reach. The Granger to Cameron reach is optimized simultaneously for *LAG* and *ATT* of 1.19 and 1.29 days, respectively.

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

Table 4.1
DAY Input DIN File for Example

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

Table 4.2
DAY Message DMS File for Example

```
  WRAP-DAY MESSAGE FILE
  Read JOBRTG record

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

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

Table 4.2 Continued
DAY Message DMS File for Example

```
 ------------------------------------------------------
 ---     ROUTED HYDROGRAPHS                        ---
 ---                                               ---
 ---     UPSTREAM GAGE NAME        Belton          ---
 ---                    LAG         1.745          ---
 ---                    ATT         1.334          ---
 ---     UPSTREAM GAGE NAME         Grang          ---
 ---                    LAG         1.188          ---
 ---                    ATT         1.288          ---
 ---     DOWNSTREAM GAGE NAME       Camer          ---
 ---                                               ---
 ------------------------------------------------------

                  ------Belton------| ------ Grang------| ------ Camer------|
                       GAGED    ROUTED     GAGED    ROUTED     GAGED     TOTAL
 YEAR  MT  N DAYS       FLOW    DNSTRM      FLOW    DNSTRM      FLOW    ROUTED
 1960   1       1     2617.0       0.0    1347.0     104.5    6039.0     104.5
 1960   1       2     1849.0    1156.4    1451.0    1158.6    8023.0    2315.0
 1960   1       3     1720.0    2277.6     877.0    1391.3    6172.0    3668.9
 1960   1       4     1842.0    1792.0     678.0     945.3    4827.0    2737.3
 1960   1       5     5833.0    1773.9     738.0     711.7    4629.0    2485.6
 1960   1       6     5347.0    3605.5    1136.0     760.1    7375.0    4365.7
 1960   1       7     4284.0    5618.2    1517.0    1107.5   11449.0    6725.8
 ...

Routing Parameter Calibration Complete
JOBRTG complete

Read JOBRTG record
Routing Parameter Calibration Complete
JOBRTG complete
```

Table 4.3
DAY Output DAY File for Example

```
  Program WRAP-DAY (July 2009 Version) Output File

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

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

*** FLOW RANGE FOR ROUTING CALIBRATION ***
GAGE NAME              Belton           Grang
LOWER FLOW LIMIT          0.0             0.0
UPPER FLOW LIMIT 1000000000.0    1000000000.0
```

Table 4.3 Continued
DAY Output DAY File for Example

```
DAYS IN TEMPORAL AND FLOW RANGE          3653
LATERAL INFLOW ADJUSTMENT METHOD            0

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

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

*** RESULTS OF OPTIMIZATION CALIBRATION ***
GAGE NAME                     Belton          Grang
OPTIMIZED LAG or K             1.745          1.188
OPTIMIZED ATT or X             1.334          1.288

OBJECTIVE FUNC 5                        188.9
LINEAR CORRELATION                       0.95
COMPUTED LATERAL INFLOW VOLUME      3436459.2
PERCENT OF ACTUAL OUTFLOW VOLUME        47.42
ACTUAL LATERAL INFLOW VOLUME        3435653.0
PERCENT OF ACTUAL OUTFLOW VOLUME        47.41

*** STATISTICS OF GAGED FLOWS AND SIMULATED DOWNSTREAM HYDROGRAPH ***
*** WITHIN THE TEMPORAL AND FLOW RANGE ***
GAGE NAME               Belton          Grang          Camer      SIMULATED
TOTAL VOLUME         2793726.0      1017505.0      7246884.0      3810424.2
PERCENT OF OUTFLOW        38.6           14.0          100.0           52.6
MEAN                     764.8          278.5         1983.8         1043.1
STANDARD DEVIATION      2419.4          806.3         5141.3         2746.5
90TH PERCENTILE         1671.4          575.0         4389.6         2311.3
75TH PERCENTILE          590.0          250.0         1696.0          877.5
50TH PERCENTILE          199.0           83.0          622.0          325.4
25TH PERCENTILE           64.0           36.0          261.0          121.5
10TH PERCENTILE           14.0           12.0          109.0           49.5

*** LINEAR CROSS-CORRELATION BETWEEN GAGED INFLOW AND GAGED OUTFLOW ***
*** WITHIN THE TEMPORAL AND FLOW RANGE ***
GAGE NAME                  Belton          Grang
TIME STEPS, OFFSET = 0      0.63            0.80
            OFFSET = 1      0.80            0.82
            OFFSET = 2      0.82            0.63
            OFFSET = 3      0.65            0.43
            OFFSET = 4      0.49            0.34
            OFFSET = 5      0.38            0.32
            OFFSET = 6      0.32            0.30
            OFFSET = 7      0.28            0.28
            OFFSET = 8      0.24            0.24
            OFFSET = 9      0.20            0.20
            OFFSET =10      0.16            0.18
```

Table 4.3 Continued
DAY Output DAY File for Example

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

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

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

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

*** RESULTS OF DIRECT CALIBRATION FOR MUSKINGUM GAGES ***
              GAGE       K       R
X = 0.00     Bryan   0.537   0.606
X = 0.10     Bryan   0.593   0.648
X = 0.15     Bryan   0.621   0.670
X = 0.20     Bryan   0.650   0.691
X = 0.25     Bryan   0.678   0.712
X = 0.30     Bryan   0.707   0.733
X = 0.40     Bryan   0.764   0.774
X = 0.50     Bryan   0.817   0.814

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

Summary of the *DAY* Routing Parameter Calibration Features

Program *DAY* determines values for the routing parameters LAG, ATT, LAGF, ATTF, MK, MX, MKF, and MXF for the single river reach defined by two control points. The optimization option also allows simultaneous calibration of routing parameters for multiple reaches defined by the same downstream control point but different upstream control points. Any number of routing parameter calibration jobs may be included in a *DAY* input dataset. For a calibration job, *DAY* reads sub-monthly (daily) flows or flow patterns from *DF* records in a DCF file. All other *DAY* input is read from a DIN file. Programs *SIMD* and *DAY* may read the same DCF file. *DAY* reads flow data for only those control points specified in the DIN file that are pertinent to that execution of *DAY*. Program *DAY* writes the values for the routing parameters determined using the alternative calibration strategies along with related input and computational results to a table contained in an output file with the filename extension DAY.

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

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

The direct Muskingum parameter calibration option based on Eqs. 4.14−4.18 computes K for assumed values of X ranging from 0.0 to 0.5. Alternatively, the user may specify a value for X. The fixed X and resulting K are output along with the linear correlation coefficient (R) defined by Eq. 2.17. The best estimate of X and corresponding K is indicated by the correlation coefficient (R) closest to 1.0.

The output table ends with flow statistics which are provided for general information in better understanding the characteristics of the flows and calibration results. Statistics are tabulated for the flows at the upstream and downstream control points used in the calibration. Lateral flow volumes are shown. Serial correlation coefficients for a range of lags are listed. The Muskingum parameter K is related to travel time or the lag between outflows and inflows. The lag with the greatest correlation coefficient provides an approximation for K.

CHAPTER 5
FLOOD CONTROL RESERVOIR OPERATIONS

Flood control reservoirs are modeled in *SIMD* as *FR* and *FF* record water rights. Operation of multiple-reservoir systems with any number of reservoirs may be based on flood flow limits at any number of downstream control points. Storage in individual reservoirs may also be governed by storage versus outflow relationships. The daily time step features described in Chapter 3 facilitate simulation of flood control operations. Most of the tables created with program *TABLES* are generally applicable to organizing *SIMD* results irrespective of whether flood control operations are included in the simulation. *TABLES* also has options for frequency analyses of annual peak flow and storage and economic damage analyses that are designed specifically for flood studies which are described in Chapter 6.

Operation of Flood Control Reservoirs

Most of the large flood control reservoirs in Texas and throughout the United States were constructed and are operated by the U.S. Army Corps of Engineers (Wurbs 1996). Exceptions include International Amistad and Falcon Reservoirs on the Rio Grande operated by the International Boundary and Water Commission, the Tennessee Valley Authority System, and multiple-purpose reservoirs constructed by the Bureau of Reclamation in the western states for which the Corps of Engineers is often responsible for flood control operations. Most of the flood control storage capacity in Texas is contained in multiple-purpose federal projects that also provide water supply and recreation and in some cases hydroelectric power.

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

Reservoirs may be operated solely for flood control, for only conservation purposes, or for both flood control and conservation. Conservation purposes include municipal and industrial water supply, agricultural irrigation, hydroelectric power, recreation, and environmental protection or enhancement. Multiple-purpose operations are based on dividing the storage capacity into conservation and flood control pools separated by a designated top of conservation pool elevation as illustrated by Figure 5.1. The top of the conservation pool is the bottom of the flood control pool. The allocation of storage capacity between pools may be constant or vary seasonally. The conservation pool storage contents are maintained as close to capacity as inflows and water demands allow. The flood control pool remains empty except during and following flood events.

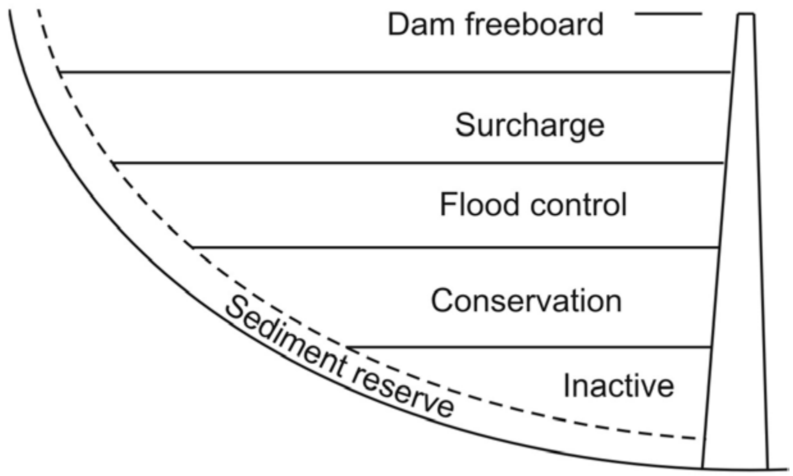

Figure 5.1 Reservoir Pools

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

Reservoir operations are based on flow limits at downstream locations as long as the flood control pool is not overtopped. During extreme flood events exceeding the flood storage capacity, flood waters may encroach into surcharge storage. With the flood control pool capacity exceeded, releases causing damages downstream are required to prevent the reservoir stage from exceeding a maximum design water surface level set based on protecting the structural integrity of the dam. If flood waters are expected to rise above the top of flood control pool, emergency operating procedures are activated with releases determined based on inflows and storage levels (Wurbs 1996, 2005). Uncontrolled spills may flow through emergency spillways.

In many cases, the allowable non-damaging channel capacity at a given river location is constant regardless of the volume of water in storage. However, operating rules may be formulated with the allowable flow rates at one or more operational control points varying depending upon the volume of water currently stored in the flood control pools. This allows stringently low flow levels to be maintained at certain locations as long as only a relatively small portion of the flood control storage capacity is occupied, with the flows increased to a higher level, at which minor damages could occur, as the reservoirs fill.

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

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

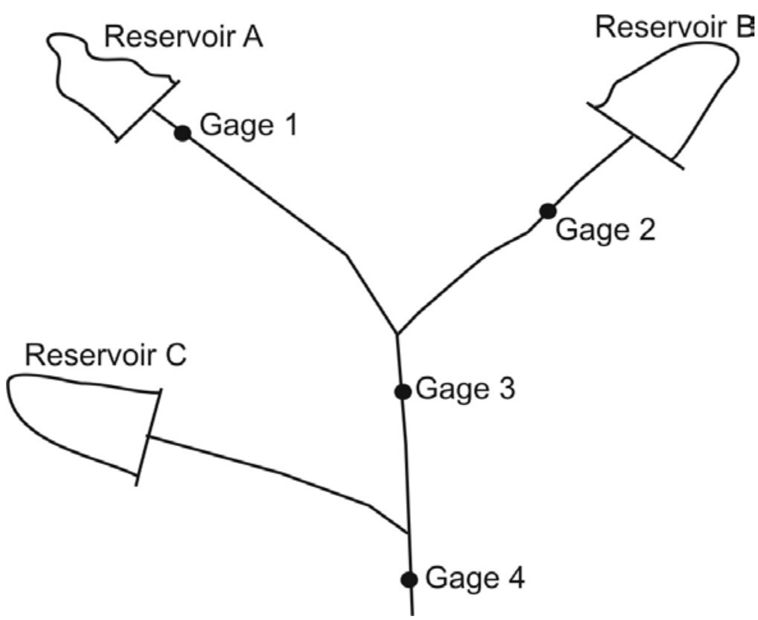

Figure 5.2 Multiple-Reservoir System Flood Control Operations

In order to minimize the risk of reservoir releases contributing to downstream flooding, operators are cautious about closing gates too late or making releases too soon. Outlet gates are opened only after some degree of confidence that flows are receding. Uncertainties regarding inflows from watershed areas below the dams and flow attenuation and travel times from the dams to the downstream control points are a key aspect of operations. Water released from a dam today may reach downstream control points several days from now. Releases combine with future unknown unregulated local inflows below the dams. Additional unexpected rainfall may occur during the time before water released from a dam reaches downstream sites on the river. Forecasting of future flows over the next several days is difficult. These uncertainties inherent in actual reservoir flood control operations are also important in *SIMD* modeling of operations.

Computer Programs, Data Files, and Input Records

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

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

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

The tables created by *TABLES* to organize simulation results are generally applicable either with or without consideration of flood control. The *7FFA* record flood frequency analysis table is the only *TABLES* option designed specifically for flood control. Frequency tables are developed for reservoir storage, naturalized flow, and regulated flow based on applying the log-Pearson type III or log-normal probability distribution to the annual series. Economic damages interpolated from a discharge or storage versus damage table may also be included in the frequency table. The *7FFA* record is included in Appendix C and discussed in Chapter 6.

Simulation of Flood Control Reservoirs

Each reservoir in a *SIMD* simulation may include either, both, or neither of the following two types of flood control operations.

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

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

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

Controlled *FR*/*FF* record pools can be operated as individual reservoirs or multiple-reservoir systems. Uncontrolled *FR*/*FV*/*FQ* record storage pools are always operated individually without multiple-reservoir system interconnections. A particular reservoir may include either or both types of operations. Reservoirs may be operated in *SIMD* for conservation purposes only with no flood control features at all or may include both conservation and flood control features.

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

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

Reservoir Pools

In *SIMD*, a reservoir consists of any or all of the four pools shown in Figure 5.3. *SIM* includes only the bottom two pools. In either *SIM* or *SIMD*, inactive and conservation pool storage capacities are specified on storage *WS* records associated with water right *WR* records. Additionally, *SIMD* allows controlled and uncontrolled flood storage to be specified by *FR/WS* record pairs. A reservoir may contain any combination of one or more pools defined as follows.

Flood Control Pool.− A flood control pool defined by *FR* record fields 8 and 10 may include zones with outflows through either controlled (gated) or uncontrolled (ungated) outlet structures. The zones are separated by the storage level entered in *FR* record field 9.

Uncontrolled Flood Control Storage.− Uncontrolled means that releases are controlled by the hydraulic design of outlet structures that have no gates operated by people. Outflow from an individual reservoir is specified as a function of storage level based on interpolation of a storage versus outflow table provided on *FV* and *FQ* records.

Controlled Flood Control Storage.− Controlled means that releases are through gated outlet structures with release decisions based on maximum allowable flows at downstream control points specified on *FF* records. Any number of reservoirs may be operated as a system to control river flows at any number of downstream control points. Flows during the current day and forecast period are considered.

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

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

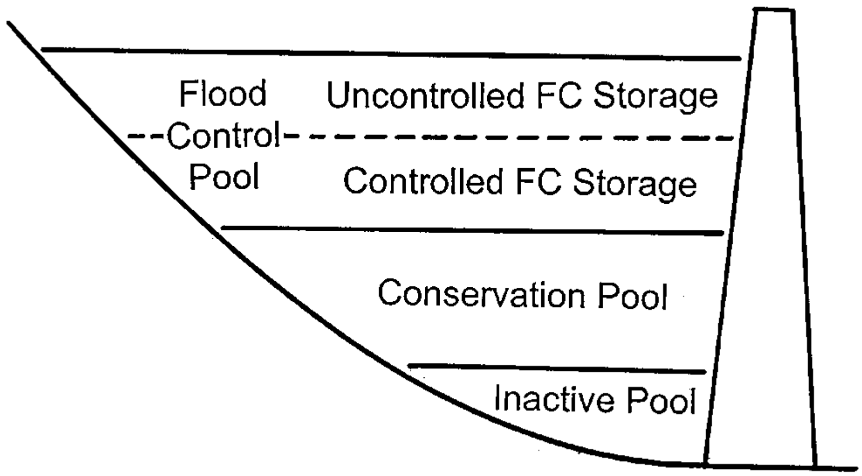

Figure 5.3 Reservoir Pools Defined by *SIMD WS* and *FR* Records

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

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

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

Reservoir Operations

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

From the perspective of storing inflows, the total storage capacity at the top of conservation pool and top of flood control pool are specified in *WS* record field 3 and *FR* record field 8, respectively. Storage is filled to these levels by *WR* and *FR* record rights, respectively. If a conservation pool is not full when a *FR* record impounds flood flows, the empty conservation space is filled as the storage level rises into the flood control pool. Any number of *FR/WS* and *WR/WS* record rights with different storage capacities may be assigned to the same reservoir. Junior rights must have storage capacities equaling or exceeding senior rights in the same reservoir. As *WR* or *FR* record rights are considered in priority order, reservoir storage is filled up to the specified storage capacity subject to the limitation of available stream flow.

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

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

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

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

Routing Flows Through River/Reservoir Systems

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

SIMD algorithms applying the attenuation and lag method and Muskingum adaptation for routing flow changes through river reaches are described in Chapter 3. The *SIM/SIMD* linear channel loss equation is described in the *Reference Manual*. The routing and channel loss methodologies are used to adjust flows at downstream control points for the effects of stream flow depletions associated with storing flood waters and the effects of subsequent releases from flood control storage. Flow routing simulates lag and attenuation. Storing and subsequent releasing of inflows to flood control pools may affect regulated flows at downstream control points in future days as well as in the same day that the flood flows are stored or released.

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

The *JU* record FRMETH switch provides two options for organizing the routing of flow adjustments from one day to the next. This feature is designed to help define the impact of flood control on *WR* record water rights. One option performs the routing of flow adjustments totally within the priority-based water rights simulation loop. Impacts of junior flood control operations on senior *WR* record water rights are minimized. The other option places flow adjustments routed from the preceding day at the beginning of the next-day simulation before the water rights loop. Senior rights may be affected by flood control activities occurring during preceding days. For example, *WR* record water supply diversion rights will have access to stream flows released from flood control pools. Storing flood waters may affect storage levels in conservation pools regardless of placement of routed flow adjustments in the simulation process.

Forecasting of Future Flows

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

Table 5.1
Simulation of Controlled Reservoir Flood Control Operations

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

<u>*Final Normal Simulation*</u>.− The simulation is repeated for one time step (day) with all features activated. Flood control operations are modeled as follows.

1. For multiple-reservoir systems, reservoirs are prioritized based on beginning-of-day storage and parameters from the *FR* records. Each individual reservoir is assigned a relative priority, which may vary daily, that governs sequencing of operating decisions.

2. Flood waters are stored as each *FR* record right is considered in priority order. A yes or no decision is made regarding closing the outlet gates controlling the flood control pool.

   a. Flows at each pertinent *FF* record control point located at or downstream of the dam are checked. A flood is declared to be in progress or imminent if the regulated flow in the current day or flow estimate in any day of the forecast period at one or more control points exceeds the flow limit from the *FF* record.

   b. If a flood is declared, flood gates for the *FR* record right are completely closed, filling storage in the standard manner applied for all *WR* and *FR* record rights.

3. Flood control pools are emptied as flood waters recede. A decision is made regarding whether or not to release water and, if so, the amount to be released.

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

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

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

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

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

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

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

<u>Controlled Reservoir Flood Control Operations</u>

The *SIM/SIMD* simulation process outlined in Figure 2.2 of the *Reference Manual* is organized based on a water rights priority loop nested within a period loop. A two-phase simulation strategy for incorporating forecasting in *SIMD* is outlined in Table 3.5 of the preceding Chapter 3. Flood control operation features of *SIMD* defined by sets of *FR* and *FF* records are embedded within the overall simulation process as outlined in Table 5.1.

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

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

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

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

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

Uncontrolled Flood Control Storage

The outlet structures of a flood control reservoir or flood retarding dam may be uncontrolled with no gates and thus no gate operations by people. Outflows are controlled by the hydraulic design of the outlet structure with no release decisions by human operators. The hydraulics are modeled with a storage-outflow table provided on *FV* and *FQ* records.

Reservoirs with controlled flood control pools and/or conservation pools with releases through gated outlet structures may also have uncontrolled spillways. With the controlled pools full of water, even with all gated outlets closed, spills may flow over an uncontrolled spillway. Uncontrolled spillways or gated spillways operated in accordance with emergency flood regulation plans may control surcharge storage in reservoirs that also have controlled flood control storage. Spills may also be routed through an uncontrolled spillway with a crest elevation at the top of conservation pool at a water supply only reservoir that has no actual flood control storage. Surcharge storage in the water supply reservoir occurs incidentally due to the limited outflow capacity of the spillway. These situations may also be modeled in *SIMD* with storage versus outflow relationships provided on *FV* and *FQ* records.

Routing of flood flows through reservoirs based on a *FV/FQ* record storage-outflow relationship is applicable to individual reservoirs but not to multiple-reservoir systems. Forecasting and *FF* records are not relevant for uncontrolled structures. Outflows are governed by storage and inflows at the reservoir in the current day.

With a set of *FV* and *FQ* records connected to a *FR* record right, whenever the storage contents exceed a specified volume, the outflow is determined by linear interpolation of the table of storage volumes versus outflow volume/period. As the *FR* record right is considered in the water rights priority loop, routing flow through the reservoir consists of the following two tasks.

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

Flood Flow Limits Defined by *FF* Records

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

Table 5.2
Flood Flow *FF* Record Input Variables

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

A *FF* record monthly flood flow limit is set similarly to an *IF* record instream flow target and *WR* record diversion and hydropower targets. An annual flow limit from a *FF* record is combined with monthly coefficients from *UC* records to obtain monthly volumes. A monthly target may be further adjusted by *DI/IS/IP*, *SO*, *FS*, and *TO* record options described in the *Users*

Manual. The flood index entered in *FF* record field 6 is connected to *IS* and *IP* records and applied identically as the drought index used with *WR* and *IF* records. The monthly target setting routines are essentially identical for *FF*, *IF*, and *WR* record targets. The resulting monthly volume is divided by the number of days in the month to obtain a daily volume.

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

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

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

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

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

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

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

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

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

2. C_{FF} for any day of the forecast period at any of the downstream control point identified by *FF* records.

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

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

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

Reservoir Operating Rules Defined by *FR* Records

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

Table 5.3
Flood Control Reservoir *FR* Record Input Variables

Field	Description
1	Record identifier (FR)
2	Control point identifier of reservoir location
4	Storage priority number
4	Release priority number
5	Number of *FF* record limits, default = all
6	FCDEP option switch
7	Maximum release volume per time interval
	Storage Volumes
8	Maximum capacity for filling flood control storage
9	Storage capacity activating *FV/FQ* record table
10	Minimum storage capacity for flood releases
	Multiple-Reservoir System Balancing
11	Multiplier factor M, default = 1.0
12	Addition factor A, default = 0.0
	Optional Water Right Identifiers
13	Water right identifier for storage right
14	Water right identifier for release right

Storage Levels

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

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

Field 9: Activation of FV/FQ record table – A non-zero (non-blank) field 9 activates routing with a *FV/FQ* record storage-outflow table if the storage rises above this level.

Field 10: Bottom of controlled flood control pool – Controlled flood control releases are not made from storage below this level. This level could be the top of conservation pool, top of inactive pool, or any other pool level defining the lower limit of the storage range for flood control releases.

A single *WS* record must follow each *FR* record or a group of *FR* records for the same reservoir. Appendix A contains further description of *FR/WS* pairs. The beginning-of-simulation storage contents of the flood control reservoir may be entered in *WS* record field 8 with the default for flood control reservoirs is to begin the simulation empty. *WS* record field 8 should be left blank or set to zero for flood control reservoirs in most cases. *WS* record field 8 is interpreted as setting the beginning of conservation storage only when paired with a *WR* record.

Priority System for Sequencing of Simulation Computations

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

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

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

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

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

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

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

Options Related to Storing Stream Flow in Flood Control Pools

Four basic tasks performed by *SIM* and *SIMD* as each water right is considered in the priority sequence are described in Table 3.4 of Chapter 3. Task 1 consists of determining the amount of stream flow available to the right based on the control point flow availability array. The switch parameter FCDEP entered in flood control reservoir *FR* record field 6 provides two alternative options for performing task 1 when filling storage in a flood control pool.

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

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

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

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

Multiple-Reservoir System Operations

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

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

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

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

Equation 5.3 can be written more concisely as Equation 5.4.

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

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

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

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

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

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

Storage-Area Relationship

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

Summary of Reservoir Operating Rules

The following discussion does not include releases through ungated or fixed-opening gated structures from single-reservoir surcharge storage modeled with a storage-outflow relationship defined by *FV* and *FQ* records. Application of *FV* and *FQ* records is covered earlier in the chapter. The following discussion focuses on controlled flood control storage.

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

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

A maximum reservoir release rate may be entered in *FR* record field 7 in dimensions of volume per daily or other sub-monthly time interval adopted. This flow limit is equivalent to the daily flow limit derived from the *FF* record field 3 annual flood flow limit but differs as follows.

- The reservoir release limit is entered directly as a volume/day in *FR* record field 7. The flood flow limit starts as a volume/year entered on a *FF* record, with the daily rate then computed based on a *UC* record and optionally further adjusted based on *TO*, *SO*, *FS*, and *DI* records in the same manner as *IF* record instream flow targets.
- The *FR* record maximum release limit applies only to the one reservoir.
- The *FR* record maximum release limit applies only to the current day. Forecasted flows are not considered in applying the limit.

Switch parameter FRMETH in *JU* record field 7 sets whether changes in river flows caused by flood control operations (storage and releases) in preceding time steps are placed within the priority sequence or at the beginning of the priority sequence in each time step. FRMETH option 2 adheres to the priority sequence, but option 1 circumvents priorities. Maintaining the priority system is typically important and thus option 2 is probably best from a water supply perspective. FRMETH option 1 may affect the amount of water available to water rights in the priority sequence. However, option 1 is typically best for flood control operations. Effects of the flood control reservoirs on each other are more accurately modeled with option 1.

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

- Gates are closed, storing available inflows, if flood conditions are declared based on comparing river flows to *FF* record allowable flood flow limits at control points located at or downstream of the reservoir and the *FR* record field 7 maximum release limit. Inflows are stored subject to not exceeding the total storage capacity at the top of flood control pool specified in *FR* record field 8.

- Releases are governed by the *FF* record flow limits, *FR* record outflow limit, and operating rules previously discussed as long as the storage contents is between the limits defined by *FR* record fields 8 and 10. *FR* record flood releases are not made if the storage level falls below the bottom of flood control pool defined in field 10. Outflow equals inflow after the flood control storage capacity is completely filled to the top of flood control pool level defined in *FR* record field 8.

- If the *FR* record field 9 option is activated, the *FV/FQ* record storage-outflow hydraulics relationship controls outflows any time the storage is at or above the level specified in field 9. An iterative algorithm determines the outflow volume during the day based on averaging beginning-of-day and end-of-day storage volumes.

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

Examples of Modeling Flood Control Reservoir Operations

Modeling reservoir operations for flood control is of course important in applications dealing specifically with flood control. However, modeling of flood control operations is also important in evaluating water supply capabilities and environmental instream flow requirements. In a *SIM* or *SIMD* monthly or daily simulation, without *FR* record flood control storage, no water is stored above the top of conservation pool storage capacities defined by the *WS* records. Whenever a reservoir is full to conservation pool capacity, inflows pass through the reservoir instantaneously without storage. However, in reality, storage in flood control pools and associated releases from flood control pools can significantly affect water supply reliabilities, regulated stream flows, and reliabilities of meeting environmental instream flow requirements.

The five daily simulation examples provided in the Chapter 7 begin with Example 7.1 which consists of converting the monthly *Fundamentals Manual* example to a daily time step. Reservoir flood control operations are added in the second example of Chapter 7. Operation of the five reservoirs for flood control is based on additional information entered on *FR* and *FF* records in the *SIMD* input DAT file. *SIMD* simulation results are organized with *TABLES* to facilitate analyses from various flood control and conservation perspectives. The examples of Chapter 7 provide comparisons of simulation results with a daily versus monthly time step and with and without considering operation of the flood control pools of the reservoirs.

WRAP flood control modeling capabilities are further illustrated by the Brazos River Basin case study reported in TWRI TR-389 (Wurbs, Hoffpauir, and Schnier 2012). A system of nine major Corps of Engineers multipurpose reservoirs are operated for flood control.

Annual flood frequency analysis of *SIMD* daily simulation results is covered in the following Chapter 6. The 7FFA record activates the flood frequency analysis capabilities of *TABLES* as described in Chapter 6 and illustrated by Examples 7.2 and 7.3 in Chapter 7.

CHAPTER 6
FREQUENCY ANALYSES

The results of a *SIM*, *SIMD*, or *SALT* simulation are viewed from the perspective of frequency, probability, percentage-of-time, and reliability metrics associated with stream flows, reservoir storage, water supply diversions, hydroelectric energy production, and salinity concentrations. These metrics for estimating and communicating likelihood are covered in various chapters of the *Reference*, *Users*, *Salinity*, and *Daily Manuals*. This present *Daily Manual* Chapter 6 summarizes those features that are covered elsewhere in the WRAP manuals as well as introducing additional features that are not covered elsewhere. The new topics introduced in this chapter include flood frequency analysis and the HEC-SSP.

Overview Summary of WRAP Reliability and Frequency Analyses

Table 6.1 lists the various parts of the WRAP manuals that cover reliability and frequency analysis capabilities. The basic reliability and frequency analysis methodologies of the WRAP program *TABLES* presented in the *Reference* and *Users Manuals* were originally developed for application to the results of a monthly *SIM* simulation but are also applicable to the results of a daily *SIMD* simulation. The 6REL record activating a reliability analysis for daily diversion requirements is equivalent to the 2REL record which applies to monthly diversion requirements. Likewise, the 6FRE, 6FRQ, and 6RES records that develop frequency analysis tables for daily simulation results are analogous to the 2FRE, 2FRQ, and 2RES records that develop frequency analysis tables for monthly simulation results. Appendix C of this *Daily Manual* describes Type 6 input records for *TABLES*, which consists of 6FRE, 6FRQ, and 6RES records and time series records, along with types 5 and 7 records. *TABLES* type 2 records along with other record types are covered in Chapter 4 of the *Users Manual*.

TABLES types 2 and 6 records deal with monthly and daily, respectively, simulation results. 2RES and 6RES records build three tables summarizing reservoir storage contents that include storage and draw-down frequency relationships. 2REL and 6REL records build diversion and hydropower reliability tables. 2FRE, 2FRQ, 6FRE, and 6FRQ records, combined with the DATA record, build frequency tables for any of the simulation results variables.

Short-term conditional reliability modeling (CRM) is described in Chapter 7 of the *Reference Manual*. *TABLES* 2REL, 2FRE, 2FRQ, and 2RES records are applied in short-term CRM as well as conventional long-term reliability and frequency analyses. The resulting 2REL, 2FRE, 2FRQ, and 2RES record tables include CRM parameters in the headings but otherwise have the same appearance as long-term analysis. The quantities in the tables are interpreted differently as explained in the *Reference Manual*. A *SIMD* CRM simulation can be performed with a daily computational time step, but the results are aggregated to monthly for reliability and frequency analyses. Thus, 6REL, 6FRE, 6FRQ, and 6RES records are not applicable for CRM.

Salinity simulation capabilities are documented by the *Salinity Manual*. Frequency analyses of salt loads and concentrations of stream flow and reservoir storage are performed with 8FRE and 8FRQ records, which are analogous to 2FRE and 2FRQ records. The frequency analysis computations are the same regardless of the variable from the *SIM* or *SALT* simulation results dataset that is being analyzed. The 8REL record is analogous to the 2REL record.

Simulation of reservoir operations for flood control is covered in the preceding Chapter 5. Flood frequency analysis capabilities are outlined later in Chapter 6.

Frequency analyses of *SIM*, *SIMD*, and *SALT* simulation results can also be performed with the *HEC-SSP Statistical Software Package* available from the Hydrologic Engineering Center (2010). As discussed later in this chapter, *HEC-SSP* provides both flexible graphics and comprehensive frequency analysis computational capabilities.

Table 6.1
Outline of Sections of Manuals Dealing with Frequency and Reliability Analyses

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<u>*Reference Manual*</u>

Chapter 2 Overview
- Measures of Water Availability and Reliability
  - (Volume and Period Reliability, Shortage Metrics, Frequency Analyses)

Chapter 5 Organization and Analysis of Simulation Results
- DATA Record Transformation of Simulation Results Data
- Reliability and Frequency Tables
- Water Supply and Hydropower Reliability
- Flow and Storage Frequency Analyses
- Reservoir Contents, Drawdown Duration, and Storage Reliability

Chapter 6 Additional Auxiliary Modeling Features
- Yield versus Reliability Relationships Including Field Yield

Chapter 7 Short-Term Conditional Reliability Modeling

<u>*Users Manual*</u>

Chapter 4 Program *TABLES*
- DATA Record – Data Transformation for Time Series and Frequency Tables
- 2REL Record – Diversion or Hydropower Reliability Summary
- 2FRE Record – Flow-Frequency or Storage-Frequency Relationships
- 2FRQ Record – Frequency for Specified Flow or Storage
- 2RES Record – Reservoir Content, Draw-Down Duration, and Storage Reliability
- 5CRM, 5CR1, 5CR2 Records – Conditional Reliability Modeling

<u>*Salinity Manual*</u>

8FRE, 8FRQ, and 8REL records

<u>*Daily Manual*</u>

Chapter 6 Frequency Analyses

Chapter 7 Examples Illustrating Daily Simulation Capabilities

Appendix C Instructions for Preparing *TABLES* Input Records
- 6REL Record − Water Supply Diversion or Hydropower Reliability
- 6FRE Record − Flow or Storage Frequency Relationships
- 6FRQ Record − Frequency for Specified Flow or Storage
- 6RES Record − Reservoir Storage and Drawdown Frequency
- 7FFA Record − Flood Frequency Analysis

Reliability Metrics for Water Supply and Hydroelectric Power

Reliability tables for meeting water supply diversion or hydroelectric energy generation requirements are developed with the monthly 2REL record or daily 6REL record. A reliability table contains both volume and period reliabilities. Period reliabilities are developed for supplying specified percentages of the *SIMD* daily demand (6REL record) and *SIM* or *SIMD* monthly and annual demands (2REL and 6REL records). Examples of 2REL and 6REL diversion reliability tables are provided in Tables 7.13 and 7.14 of Chapter 7.

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

$$R_V = \frac{v}{V}\ (100\%) \tag{6.1}$$

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

Period reliability is the percentage of the total number of periods of the simulation during which the specified demand target is either fully supplied or at least a specified percentage of the target is supplied. The various variations of period reliability (R_P) are computed by *TABLES* from the results of a *SIM* or *SIMD* simulation as:

$$R_P = \frac{n}{N}\ (100\%) \tag{6.2}$$

where n denotes the number of periods during the simulation for which the specified percentage of the demand target is met, and N is the total number of periods considered. The 2REL record develops a reliability table with periods defined alternatively in terms of both months and years. The 6REL record develops a reliability table from *SIMD* simulation results with periods defined alternatively in terms of both days (sub-monthly time step) as well as months and years. The 2REL and 6REL records allow N and n to be defined on a monthly basis optionally either considering all months or only months with non-zero demand targets.

Whereas volume reliabilities are based on total diversion volumes or hydroelectric energy amounts, period reliabilities are based on percent-of-time. Period reliability R_P is an expression of the percentage of time that the full demand target or a specified portion of the demand target can be supplied. Equivalently, R_P represents the likelihood or probability of the target being met in any randomly selected day, month, or year.

Volume and period reliabilities are the standard metrics adopted in most applications of WRAP. However, 2REL and 6REL record field 7 adds a shortage summary table to the standard volume and period reliability table. The metrics tabulated in the shortage summary table include the maximum shortage, vulnerability, resiliency, average severity, shortage index, average number of failures per sequence, and maximum number of consecutive shortages. These diversion shortage metrics are defined in Chapter 5 of the *Reference Manual*.

Frequency Analyses

The 2FRE, 2FRQ, 6FRE, and 6FRQ records are used to perform frequency analyses of *SIM* and *SIMD* simulation results. These *TABLES* records allow frequency analyses to be performed alternatively based on either relative frequency or the normal or log-normal probability distributions. The default relative frequency counting approach is typically adopted for most applications. However, as discussed in *Reference Manual* Chapter 5, the alternative of applying a probability distribution function may offer improvements in the accuracy of frequency estimates under appropriate circumstances.

Relative Frequency

Relative frequency is expressed by Eq. 6.3 where n is the number of days (6FRE, 6FRQ) or months (2FRE, 2FRQ) during the simulation that a particular flow or storage amount is equaled or exceeded, and N is the total number of days or months considered.

$$\text{Exceedance Frequency} = \frac{n}{N}\ (100\%) \tag{6.3}$$

Normal and Log-Normal Probability Distributions

Alternatively, the *TABLES* frequency analysis records provide options to apply the normal (Eq. 6.4) or log-normal (Eq. 6.5) probability distribution to the simulation results variables generated by *SIMD* or *SIM*.

$$X = \overline{X} + z\,S \tag{6.4}$$

$$\log X = \overline{\log X} + z\,S_{\log X} \tag{6.5}$$

$\overline{X}$ and S are the mean and standard deviation of the data from the *SIM* output file. $\overline{\log X}$ and $S_{\log X}$ are the mean and standard deviation of the logarithms of these data. The log-normal distribution consists of the normal distribution applied to the logarithms of X, with Eq. 6.4 expressed as Eq. 6.5 with z still derived from the normal probability distribution. The frequency factor (z) is derived from a normal probability table.

The random variable X in Equations 6.4 and 6.5 is the naturalized flows, regulated flows, unappropriated flows, instream flow shortages, reservoir storage volumes, or other variables from the *SIM/SIMD* simulation results or variations thereof reflecting adjustments made within *TABLES*. The mean and standard deviation computed from these data using Equations 6.6 and 6.7 are the parameters used to model frequency relationship as the log-normal or normal probability distributions. For the log-normal distribution, the mean and standard deviation of the logarithms of the data from the *SIM* output file are computed and entered into Equation 6.5.

$$\overline{X} = \frac{1}{n} \sum_{i=1}^{n} X_i \tag{6.6}$$

$$S = \left[\frac{1}{n-1} \sum_{i=1}^{n} \left(X_i - \overline{X} \right)^2 \right]^{0.5} \tag{6.7}$$

In the routines activated by the 2FRE or 6FRE record that apply the probability distribution options, exceedance probabilities are assigned to the random variable X by fitting the normal or log-normal distribution in the standard manner consistent with traditional statistical methods. The frequency factor z for specified exceedance frequencies tabulated in Table 6.2 are derived from the normal probability table and are built into *TABLES*. All of the frequencies listed in Table 6.2 are included if the results of the 2FRE/6FRE frequency computations are tabulated in columnar format. With the standard row format, several of the frequencies are omitted to reduce the width of the table.

Table 6.2
Frequency Factors for the Normal Probability Distribution

Exceedance Frequency	Factor z in Eqs. 6.4 & 6.5	Exceedance Frequency	Factor z in Eqs. 6.4 & 6.5
99.9%	−3.09023	0.1%	3.09023
99.5%	−2.57583	0.5%	2.57583
99%	−2.32637	1%	2.32635
98%	−2.05377	2%	2.05375
95%	−1.64487	5%	1.64485
90%	−1.28156	10%	1.28156
80%	−0.84162	20%	0.84162
75%	−0.67450	25%	0.67450
70%	−0.52440	30%	0.52440
60%	−0.25335	40%	0.25335
50%	0.00000		

Format Options for Frequency Tables

The 2FRE and 2FRQ record frequency tables based on monthly quantities may be based on considering all months or alternatively be developed for a specified month of the year such as May or August. Likewise, the 6FRE and 6FRQ record frequency analyses of daily quantitities may be based on considering all days of the year or alternatively be developed for only those days falling within a specified month of the year such as May or August. Optionally, frequency analysis may be applied to moving averages or moving accumulative totals of the data computed for a user-specified number of months or days. The data may be adjusted by a multiplier factor, which may be a unit conversion factor or serve other purposes. The data may be added or subtracted from a constant. For example, the time series data for a frequency analysis of reservoir draw-downs is developed by subtracting water surface elevations from the user specified top of conservation pool elevation or storage volume may be subtracted from capacity. Likewise, deviations of regulated flows from a specified flow amount may be analyzed.

Tables 7.7, 7.8, 7.9, 7.10, 7.11, and 7.12 in Example 7.1 of the next chapter were developed in row format with 2FRE (monthly data) and 6FRE (daily data) records. 6FRE tables in column versus row format are compared in Table 7.28 of Example 7.4. The 2FRQ/6FRQ records also develop frequency table for the same types of variables, but in a different format illustrated by examples in Chapter 5 of the *Reference Manual*.

Frequency Analysis Variables

In applying a 2FRE or 2FRQ record, *TABLES* reads monthly simulation results from the *SIM* or *SIMD* output OUT file. With a 6FRE or 6FRQ record, *TABLES* reads sub-monthly (daily) simulation results from the *SIMD* sub-monthly output SUB file. The *TABLES* DATA record reads all of the simulation results quantities from either a monthly OUT or daily SUB file and creates datasets to be analyzed with 2FRE, 6FRE, 2FRQ, 6FRQ, and time series records.

Exceedance frequency tables may be created with *TABLES* 2FRE, 6FRE, 2FRQ, and 6FRQ records for the following variables without using a DATA record:

- naturalized flow, regulated flow, unappropriated flow, instream flow shortage, and reservoir storage volume for specified control points
- instream flow shortages and reservoir storage volume for specified water rights
- reservoir storage volume and water surface elevation for specified reservoirs
- other variables such as reservoir draw-downs computed from these variables

Many applications of 2FRE/6FRE and 2FRQ/6FRQ frequency analysis capabilities deal with stream flows or reservoir storage without needing a DATA record. However, a DATA record allows 2FRE/6FRE/2FRQ/6FRQ frequency analyses to be performed for any of the variables in a *SIM* OUT or *SIMD* SUB output file or other daily, monthly, or annual time series developed by the DATA record from the simulation results. The2FRE/6FRE and 2FRQ/6FRQ record routines can be applied to any data series created with a DATA record.

The *TABLES* DATA record is introduced in Chapter 5 of the *Reference Manual* and further explained in Chapter 4 of the *Users Manual*. The sole purpose of the DATA record is to transform *SIM* or *SIMD* simulation results to other time series variables of interest to be accessed as input by *TABLES* frequency analysis record and/or time series record routines. Although the DATA record has broad general applicability, environmental instream flow studies based on daily *SIMD* simulation results provide a key motivation for its design. The DATA record is illustrated in Examples 7.3 and 7.4 of Chapter 7. The DATA and 6FRE records are used in Example 7.4 to develop frequency metrics for the annual series of the minimum 7-day volume of naturalized flows. Example 7.3 of Chapter 7 applies the DATA and 6FRE records as well as the 7FFA record to perform frequency analyses of maximum annual reservoir storage contents.

The 35 time series record identifiers listed in the second column of Table 6.3 represent 31 time series variables read directly from the *SIM/SIMD* output OUT file or *SIMD* sub-monthly output SUB file and four other variables computed by combining simulation result variables. The variables are defined in Chapter 5 of the *Reference Manual*. The variables are associated with either control points, water rights, or reservoirs. Several of the water right variables are also aggregated by control point or reservoir in the *SIM/SIMD* simulation results.

The DATA record converts *SIM* or *SIMD* simulation results to other related datasets that can be read by the *TABLES* time series and frequency records. All of the simulation results time series variables from the *SIM* output OUT or *SIMD* SUB output files listed in Table 6.3 can be read with a DATA record and manipulated to create other datasets consisting of daily or monthly quantities or annual totals, minima, or maxima covering a specified number of time periods defining a season of the year. Moving averages or totals may be adopted. The new dataset can be read and organized by time series records just like the original variables listed in Table 6.3. Time series record identifiers are listed in column 2 of Table 6.3. The DATA record also allows 6FRE, 2FRE, 6FRQ, and 2FRQ record frequency analyses to be performed for all of the variables listed in Table 6.3 and other derived datasets.

Table 6.3
SIM and *SIMD* Simulation Results Variables

Variable from Simulation Results	Time Series ID	Simulation Results for Specified Control Point	Water Right	Reservoir
naturalized stream flow	NAT	control point		
regulated stream flow	REG	control point		
unappropriated stream flow	UNA	control point		
channel loss	CLO	control point		
channel loss credit	CLC	control point		
return flow returned this control pt	RFR	control point		
upstream reservoir release	URR	control point		
control point inflow	CPI	control point		
reservoir storage	STO	control point	water right	reservoir
evaporation-precipitation volume	EVA	control point	water right	reservoir
stream flow depletion	DEP	control point	water right	
diversion target	TAR	control point	water right	
diversion shortage	SHT	control point	water right	
diversion	DIV	control point	water right	
hydroelectric energy target	TAR		water right	
hydroelectric energy shortage	SHT		water right	
firm energy produced	DIV		water right	
instream flow target	IFT	control point	water right	
instream flow shortage	IFS	control point	water right	
flow switch record volume	FSV		water right	
flow switch record count	FSC		water right	
return flow for water right	RFL		water right	
available stream flow	ASF		water right	
increase in available flow	XAV		water right	
secondary reservoir release	ROR		water right	
hydropower shortage	HPS			reservoir
electric energy generated	HPE			reservoir
stream flow depletions	RID			reservoir
inflows from reservoirs	RIR			reservoir
releases useable for power	RAH			reservoir
releases not accessible	RNA			reservoir
adjusted evaporation-precip depth	EPD			reservoir
evaporation-precipitation depth	EVR			reservoir
water surface elevation	WSE			reservoir
reservoir storage capacity	RSC			reservoir
reservoir drawdown volume	RSD			reservoir

HEC-SSP Statistical Software Package

The HEC-SSP Statistical Software Package software and user manual (Hydrologic Engineering Center 2010) are available from the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (http://www.hec.usace.army.mil/). The public domain software and manual can be downloaded from the HEC website free-of-charge. HEC-SSP performs frequency analyses with the results presented both in tables and graphs. HEC-SSP is comprised of the following components.

- A general frequency analysis component applies the log-Pearson type III, Pearson type III, log-normal, and normal probability distribution functions to perform frequency analyses for annual series of peak flows or other variables. The Weibull formula is also applied.
- A Bulletin 17B flood flow frequency component applies the log-Pearson type III probability distribution to annual series of peak stream flows following standard procedures outlined in Bulletin 17B of the Interagency Advisory Committee on Water Data entitled *Guidelines for Determining Flood Flow Frequency*.
- A volume frequency analysis component is designed for analyzing daily stream flow or stage data. Annual series of minimum or maximum volumes each year during durations of one or more days are analyzed based on an input daily dataset.
- A duration analysis component shows the percent-of-time that a hydrologic variable exceeds specified values.
- A coincident frequency analysis component develops an exceedance frequency relationship for a variable as a function of two other variables.
- A curve combination analysis component combines frequency curves from multiple sources into one frequency curve.

Most of the computational capabilities of HEC-SSP applicable to WRAP are also found in the WRAP program *TABLES*. However, HEC-SSP provides convenient features for plotting frequency analysis results. *TABLES* has no graphics capabilities. *TABLES* does provide capabilities for developing detailed frequency tables designed specifically for WRAP simulation results that are not included in HEC-SSP.

WRAP and HEC-SSP are convenient to apply in combination because HEC-SSP reads DSS files created by *SIM*, *SIMD*, or *TABLES*. *SIM* and *SIMD* simulation results can be recorded directly in a DSS file or alternatively can be organized by *TABLES* time series records as either columns in a text file or DSS records in a DSS file. Columns in a text file can be transported to HEC-SSP. However, DSS files provide a more convenient mechanism to transport WRAP simulation results to HEC-SSP. The HEC-DSS (Data Storage System) is used routinely with HEC simulation models and with other non-HEC modeling systems as well. The WRAP Fortran programs are linked during compilation to DSS routines from a static library file provided by the Hydrologic Engineering Center that allow access to DSS files. As discussed in the Reference Manual, the HEC-DSS Visual Utility Engine (HEC-DSSVue) is a graphical user interface program for viewing, editing, and manipulating data in HEC-DSS files that is also used with WRAP. Application of HEC-SSP is illustrated in Example 7.2 of Chapter 7. The graphs of Figures 7.3-7.19 were plotted with HEC-DSSVue.

Flood Frequency Analyses

The *TABLES* 7FFA record routines are designed specifically for flood frequency analyses of *SIMD* simulation results. The 7FFA record is described in Appendix C and applied in Example 7.2. HEC-SSP can also be used with WRAP to perform a flood frequency analysis as illustrated in Example 7.2. HEC-SSP will reproduce the basic flood frequency analysis results developed with the *TABLES* 7FFA record and also provide additional auxiliary information, that is not provided by *TABLES*, including confidence limits and frequency plots. Other tables created by *TABLES* to organize simulation results are generally applicable either with or without flood control being considered and may be adopted along with 7FFA record tables to organize the results of a simulation study of flood control operations.

SIMD has an option, activated by parameter AFF in *JT* record field 9, to write annual series of maximum naturalized flows, regulated flows, reservoir storages, and excess flows (defined below) to an output file with the filename extension AFF. The peak daily flow and storage volumes are listed for each year of the *SIMD* simulation at specified control points. These series of annual peak daily volumes are input data for the 7FFA record routines. The organization of the *SIMD* AFF file read by *TABLES* is described in Table 6.4. Peak annual series may be generated for all or selected control points. If reservoir storage is not associated with a control point in the AFF output file, a value of −1.0 is inserted in the storage column.

Table 6.4
Organization of the *SIMD* Annual Flood Frequency AFF Output File

First record is the following heading:

WRAP-SIMD Flood Frequency Analysis File

Second record contains values for the variables total number of years *NYRS* and total number of control points *NCPTS* in 2I6 format.

Third record is the column headings for the data to follow:

YEAR CPID NAT-FLOW REG-FLOW STORAGE EXCESS FLOW

The remaining data consists of an annual sequential listing with each line containing the year, control point, and maximum values of naturalized flow, regulated flow, and reservoir storage volume occurring in each year.

The parameter ID in 7FFA record field 2 allows the user to select the annual data series from the AFF file for which the frequency analysis is applied. The options are (1) maximum daily naturalized flow, (2) maximum daily regulated flow, (3) maximum daily storage contents, and (4) summation of maximum daily storage contents and total annual excess flow volume.

Adjustments to Remove Non-Homogeneity of Exceeding Controlled Storage Capacity

The excess flow volume in the last column of the *SIMD* AFF file (Table 6.4 above) is used within the *TABLES* 7FFA record frequency analysis routine to deal with the following complexity. A dataset of maximum annual reservoir storage contents is subject to non-homogeneity associated with switching between regular and emergency reservoir operations that invalidates a frequency analysis. Thus, the frequency analysis is applied to the summation of peak annual storage volume plus corresponding excess flow volume as described below.

The exceedance probability, exceedance frequency, or recurrence interval associated with filling the controlled flood control pool are meaningful measures of the flood control capacity of a reservoir. Storage-frequency relationships for the full range of flood levels also provide useful information. However, the validity of a frequency analysis is affected by the change from regular to emergency reservoir operations that occurs whenever the controlled flood control storage capacity is exceeded. Emergency operations may be modeled in *SIMD* simply by allowing outflow to equal inflow whenever the controlled flood control pool storage capacity is exceeded. Alternatively, *FV/FQ* records may be used to model surcharge storage. In either case, the non-homogeneity associated with switching between regular (*FF* record) and emergency surcharge (*FV/FQ* record) flood control operations invalidates the application of the log-Pearson III analysis directly to storage volumes. Thus, the excess flows are used to adjust the storage.

The excess flow volume tabulated in the last column of the AFF file is the total flow from the reservoir in a year that occurs during days in which the controlled flood control capacity is exceeded. These are uncontrolled spills from the surcharge pool of a full reservoir. The excess flow volume for the year is zero in years during which the controlled flood control capacity is not exceeded, which is typically most years or perhaps all years of the simulation for major flood control reservoirs. Adding the excess flow volume to the reservoir storage capacity approximates the storage contents that would have occurred in a reservoir with a controlled flood control pool that is infinitely large or at least large enough to not be overtopped during the hydrologic period-of-analysis of the simulation.

Log-Pearson Type III Model of Annual Peak Flow and Storage

The 7FFA record builds a table of daily flow or storage volumes corresponding to annual exceedance frequencies of 99, 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent, which correspond to recurrence intervals of 1.01, 2, 5, 10, 25, 50, 100, 200, and 500 years. The relationship between annual exceedance probability P and recurrence interval T in years is:

$$T = \frac{1}{P} \quad \text{or} \quad P = \frac{1}{T} \tag{6.8}$$

The flood frequency analysis computations are based on applying the log-Pearson type III probability distribution in a standard manner outlined by Wurbs and James (2002), McCuen (2005), many other textbooks, and the Interagency Advisory Committee on Water Data (1982). The frequency factor table is reproduced as Table 6.5.

The random variable X is the maximum daily (or other time period) naturalized flow, regulated flow, or end-of-period reservoir storage volume to occur in a year. The X corresponding to a given exceedance probability is determined from Equation 6.9 combined with a table relating the frequency factor K to exceedance probability P and skew coefficient G.

$$\log X = \overline{\log X} + K\, S_{\log X} \qquad (6.9)$$

The mean $\overline{\log X}$, standard deviation $S_{\log X}$, and skew coefficient $G_{\log X}$ of the logarithms of X are computed from an annual series of maximum daily flow or storage volumes X. The frequency factor K is obtained as a function of P and $G_{\log X}$ by linear interpolation of a Pearson type III probability table built into the program *TABLES*. The probability table incorporated in *TABLES* is more precise with more digits than shown in Table 6.5.

Table 6.5
Frequency Factor K for the Pearson Type III Distribution

	Recurrence Interval (years)							
Skew	1.01	2	5	10	25	50	100	200
Coef	Exceedance Frequency (percent)							
G	99	50	20	10	4	2	1	0.5
3.0	-0.667	-0.396	0.420	1.180	2.278	3.152	4.051	4.970
2.8	-0.714	-0.384	0.460	1.210	2.275	3.114	3.973	4.847
2.6	-0.769	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.4	-0.832	-0.351	0.537	1.262	2.256	3.023	3.800	4.584
2.2	-0.905	-0.330	0.574	1.284	2.240	2.970	3.705	4.444
2.0	-0.990	-0.307	0.609	1.302	2.219	2.912	3.605	4.398
1.8	-1.087	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.6	-1.197	-0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.4	-1.138	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.2	-1.449	-0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.0	-1.588	-0.164	0.758	1.340	2.043	2.542	3.022	3.489
0.8	-1.733	-0.132	0.780	1.336	1.993	2.453	2.891	3.312
0.6	-1.880	-0.099	0.800	1.328	1.939	2.359	2.755	3.132
0.4	-2.029	-0.066	0.816	1.317	1.880	2.261	2.615	2.949
0.2	-2.178	-0.033	0.830	1.301	1.818	2.159	2.472	2.763
0.0	-2.326	0.000	0.842	1.282	1.751	2.054	2.326	2.576
-0.2	-2.472	0.033	0.850	1.258	1.680	1.945	2.178	2.388
-0.4	-2.615	0.066	0.855	1.231	1.606	1.834	2.029	2.201
-0.6	-2.755	0.099	0.857	1.200	1.528	1.720	1.880	2.016
-0.8	-2.891	0.132	0.856	1.166	1.448	1.606	1.733	1.837
-1.0	-3.022	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.2	-3.149	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.4	-3.271	0.225	0.832	1.041	1.198	1.270	1.318	1.351
-1.6	-3.388	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.8	-3.499	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-2.0	-3.605	0.307	0.777	0.895	0.959	0.980	0.990	0.995
-2.2	-3.705	0.330	0.752	0.844	0.888	0.900	0.905	0.907
-2.4	-3.800	0.351	0.725	0.795	0.823	0.830	0.832	0.833
-2.6	-3.899	0.368	0.696	0.747	0.764	0.768	0.769	0.769
-2.8	-3.973	0.384	0.666	0.702	0.712	0.714	0.714	0.714
-3.0	-4.051	0.396	0.636	0.660	0.666	0.666	0.667	0.667

Equations for the sample mean, standard deviation, and skew coefficient are as follows.

$$\bar{X} = \frac{1}{n} \sum_{i=1}^{n} X_i \tag{6.10}$$

$$S = \left[\frac{1}{n-1} \sum_{i=1}^{n} \left(X_i - \bar{X} \right)^2 \right]^{0.5} \tag{6.11}$$

$$G = \frac{n \sum_{i=1}^{n} \left(X_i - \bar{X} \right)^3}{(n-1)\,(n-2)\, S^3} \tag{6.12}$$

The frequency table created by the 7FFA record also includes the expected value of the flow or storage. The expected value is a probability-weighted average.

Log-Normal Probability Distribution

With a skew coefficient value of zero, the log-Pearson type III distribution is identical to the log-normal probability distribution. The values for K in Table 6.5 for a G of zero are the same as the values from normal probability tables. Thus, a frequency analysis based on the log-normal distribution may be performed with *TABLES* by specifying a skew coefficient of zero on the 7FFA record.

The log-normal probability distribution is applied extensively in modeling hydrologic variables. The log-normal distribution is equivalent to applying the normal (Gaussian) probability distribution to the logarithm of the random variable. Unlike the normal distribution, the log-normal and log-Pearson III distributions assign non-zero probabilities to only ranges of positive values of the random variable. With the log-normal or log-Pearson III distribution, the random variable has a probability of zero of being less than zero, which is appropriate for many variables including stream flow and reservoir storage.

The log-normal probability distribution has only two parameters, the mean and standard deviation. The log-Pearson type III distribution provides greater flexibility than the log-normal in that a third parameter, the skew coefficient, allows the skewness of the probability density function to be adjusted. However, as discussed in the next section, the accuracy of estimates of the skew coefficient is significantly limited by sample size.

Skew Coefficient

The skew coefficient G computed with Eq. 6.12 is particularly sensitive to extreme flood events due to the cube term. Estimates from small samples may be inaccurate. Thus, Bulletin 17B of the Interagency Advisory Committee on Water Data (1982) provides a generalized skew map for flood flows that is reproduced by Wurbs and James (2002), McCuen (2005), and other references. Depending on the number of years of gage record, regionalized skew coefficients are used either in lieu of or in combination with values computed from observed flows at the location of concern.

Equations 6.13-6.18 allow a weighted skew coefficient G_W for flood flows to be computed by combining a regionalized skew coefficient G_R and station skew coefficient G.

$$G_W = \frac{(MSE_R)(G)+(MSE_S)(G_R)}{MSE_R + MSE_S} \tag{6.13}$$

$$MSE_S = 10^{[A-B(Log_{10}(N/10))]} \tag{6.14}$$

$$A = -0.33+0.08|G| \quad \text{if} \quad |G| \leq 0.90 \tag{6.15}$$

$$A = -0.52+0.30|G| \quad \text{if} \quad |G| > 0.90 \tag{6.16}$$

$$B = 0.94-0.26|G| \quad \text{if} \quad |G| \leq 1.50 \tag{6.17}$$

$$B = 0.55 \quad \text{if} \quad |G| > 1.50 \tag{6.18}$$

The station skew G is computed from the logarithms of the observed flows using Eq. 6.12. The regional skew G_R is either developed from multiple stations following procedures outlined in Bulletin 17B or read from the generalized skew coefficient map also supplied by Bulletin 17B. The generalized regional skew coefficients G_R are for the logarithms of annual maximum stream flow. MSE_S denotes the mean square error of the station skew. MSE_R is the mean square error of the regional skew. Bulletin 17B sets the MSE_R at 0.302 if G_R is taken from the generalized skew map.

The 7FFA record in *TABLES* provides options for determining the skew coefficient G for the logarithms of the annual peak naturalized and regulated flow and storage volumes. By default, the program computes G with Eq. 6.13. Alternatively, G may be computed external to the program and entered as input. As another option, the regionalized skew coefficient G_R may be entered as input and combined with G internally within the program based on Eqs. 6.13-6.18 to determine weighted skew coefficient G_W. The program uses a MSE_R of 0.302 from Bulletin 17B.

Listing of Annual Peaks with Weibull Probabilities

The *7FFA* record will also create a tabulation of peak annual naturalized and regulated flows and reservoir storage with exceedance frequencies assigned by the Weibull formula. The Weibull formula estimates exceedance probabilities based on relative frequency as follows:

$$P = \frac{m}{N+1} \tag{6.17}$$

where P denotes annual exceedance probability, m is the rank of the values (m = 1, 2, 3, ... , N), and N is the total number of years in the data series. The greatest flow or storage volume is assigned a rank (m) of 1, and the smallest is assigned a rank of N.

HEC-SSP Statistical Software Package

HEC-SSP performs a flood frequency analysis as outlined above and will reproduce the results obtained with the *TABLES* 7FFA record routine. HEC-SSP also computes confidence limits and expected probability adjustments which are not provided with the 7FFA record. HEC-SSP plots the frequency analysis results. Example 7.2 in Chapter 7 includes flood frequency analyses performed with both the *TABLES* 7FFA routine and HEC-SSP. HEC-SSP is documented in detail by a users manual (Hydrologic Engineering Center 2010, http://www.hec.usace.army.mil/).

Economic Flood Damages

The frequency table developed with *TABLES* is expanded to a frequency and damage table with addition of 7VOL and 7DAM records following the 7FFA record. 7VOL and 7DAM records provide a table of daily stream flow or reservoir storage volume versus damage. The 7DAM record contains flood damages in dollars (or other units) corresponding to the stream flow or storage volumes on the 7VOL record. Economic flood damages in dollars are normally entered on a 7DAM record. However, the damage function may be generically treated as a penalty function with other devised units. *TABLES* assigns damages to the volumes in the frequency table by linear interpolation of the 7VOL/7DAM record table. The resulting frequency/damage table includes the volume and damage for each frequency and also average annual damages.

Average annual damage or the expected value of annual damages, in dollars, is a probability-weighted average of the full range of possible of possible flood magnitudes. Flood damages in different years may range from none to catastrophic. The *average annual damage* represents the average that might be expected to occur over an extremely large number of years or the damages that may be expected to occur, on average, in any future year. The terms *expected* and *average* annual damage are used interchangeably. The expected value of annual damage is determined by numerical integration of the exceedance frequency versus damage relationship. The methodology outlined in Section 11.3 of Wurbs and James (2002) is incorporated into *TABLES*.

The expected value of both the flow volume or storage and the damages are included in the table determined using the same numerical integration algorithm. The expected value of flow volume or storage is included in the 7FFA record frequency analysis table even if the 7VOL/7DAM record economic analysis is not activated.

CHAPTER 7
DAILY MODELING SYSTEM EXAMPLES

The examples of applying *SIMD* and *TABLES* in this chapter illustrate the daily time step modeling, flood control simulation, and frequency analysis capabilities covered in Chapters 2, 3, 5, and 6 of this *Daily Manual* and capabilities for modeling environmental instream flow requirements covered in the basic *Reference Manual*. The five examples in this chapter are daily time step extensions of the monthly example presented in the *Fundamentals Manual*.

- Example 7.1 converts the monthly dataset to daily.
- Example 7.2 adds flood control.
- Examples 7.3 and 7.4 apply frequency analysis methods to annual series created from daily data. Example 7.3 deals with annual series of maximum reservoir storage levels. Example 7.4 develops annual series of minimum 7-day naturalized flow volumes that are used in Example 7.5.
- Example 7.5 focuses on building targets for instream flow requirements.

The example presented in the *Fundamentals Manual* was adapted from the TCEQ WAM dataset for the Brazos River Basin and Brazos-San Jacinto Coastal Basin, called the Brazos WAM, which has about 700 reservoirs and over 3,000 control points. The example is reduced to a system of six reservoirs, 11 control points, and hypothetical water management and use requirements. The expanded modeling capabilities documented in this *Daily Manual* have also been applied using the complete TCEQ Brazos WAM dataset (Wurbs, Hoffpauir, and Schnier 2012). Hoffpauir (2010) applied earlier developmental versions of *SIMD* to the Brazos WAM during the development of the *SIMD* daily modeling capabilities.

The *Fundamentals Manual* is organized around an example of a monthly WRAP simulation of the system shown in Figure 7.1, which consists of eleven control points, six reservoirs, and 30 water rights. The hydrologic period-of-analysis is 1940-1997. Descriptions of the river/reservoir/use system along with input files and simulation results are presented in the *Fundamentals Manual*. Expanded versions of the *Fundamentals Manual* example are presented in Chapters 4, 7, and 8 of this *Daily Manual*. The examples here in Chapter 7 illustrate the application of daily time step and flood control modeling capabilities of *SIMD* and *TABLES*. Modeling of environmental instream flow requirements is also explored. The input files for all of the examples presented in all of the manuals, including the examples presented in this chapter, are available in electronic format along with the WRAP executable programs.

The five daily time step examples of this chapter use all of the *SIM* input files of the original monthly example from the *Fundamentals Manual* with additional data added as needed. The original FLO and EVA files are adopted without change. The DAT file is modified as needed and a DCF file is created to develop the daily *SIMD* input dataset.

***SIMD* Input Records Associated with a Sub-Monthly (Daily) Simulation**

The types of *SIMD* input records used with sub-monthly (daily) time step simulation features are listed in Table 7.1 and explained in Appendix A. Each field of each of these input records is described in Appendix A. The input records are stored in DAT and DCF files.

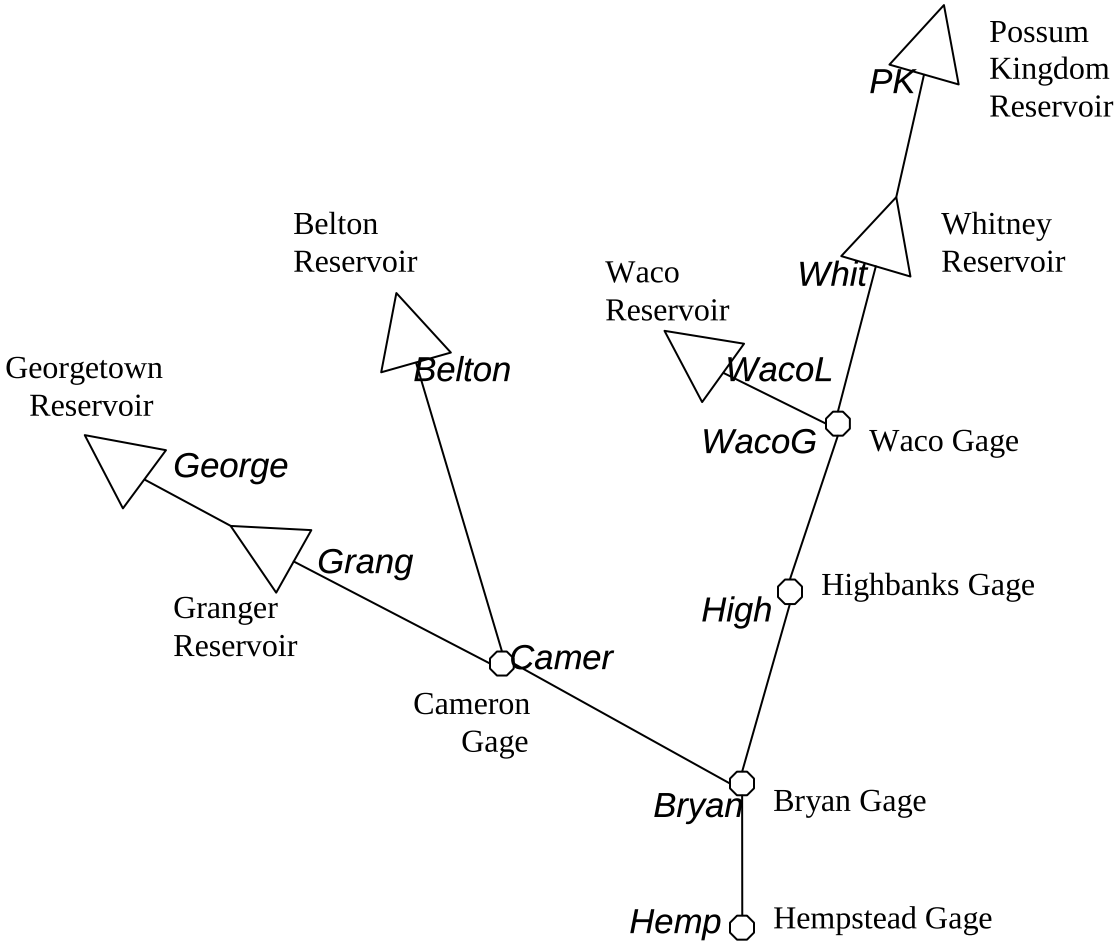

Figure 7.1 System Schematic for the Examples

Table 7.1
SIMD Input Records for Daily Simulations

Sub-Monthly Time Step Records in DAT File	
JT	sub-monthly time step job control
JU	sub-monthly job options
TI	sub-monthly time intervals
W2, *C2*, *C3*, *G2*, *R2*	simulation results output control
DW, *DO*, *PF*, *PO*	sub-monthly water rights and target data
FR, *FF*, *FV*, *FQ*	reservoir operations for flood control
Records in DCF File	
DW/SC, *DO/SC*	optional placement of DW and DO records
RT, *DC*, *DF*	routing, disaggregation, and daily flow data

The *JT* record is the only additional required record that must be added to a *SIM* input dataset to activate a *SIMD* daily simulation. The other records listed in Table 7.1 are optional.

The *TI* record allows each of the 12 months of the year to be sub-divided into any integer number of intervals from 2 to 32. However, with a zero in *JT* record field 2, this example adopts the default of defining sub-monthly intervals as daily with the number of intervals in each month being 28 or 29 in leap years for February and 30 or 31 for the eleven other months.

The *W2*, *C2*, *C3*, *G2*, and *R2* records in combination with *JT* record fields 3, 4, and 10 control the selection of simulation results output to be recorded in the SUB and AFF files. The −1 entered in *JT* record fields 3 and 4 for these examples means that daily simulation results will be recorded in the *SIMD* output SUB file for all control points and all water rights. Though not a concern with these relatively small examples, the SUB file may become extremely large for datasets with numerous control points, reservoirs, and water rights. The *W2*, *C2*, *G2*, and *R2* records allow selection of a limited number of water rights, control points, and reservoirs for inclusion in the SUB file. The *C3* record allows selection of control points for inclusion in the flood frequency analysis AFF output file for a non-zero entry in *JT* record field 10. An AFF output file is added in Example 7.2 in conjunction with analyzing flood control.

The *DW* and *DO* records control various options for modeling water rights including daily target distribution and target setting options and forecast periods. Defaults set on the *JU* record apply to all water rights unless replaced by *DW* records for individual rights. Forecast and routing periods are automatically determined within *SIMD* unless superseded by parameters entered on *JU* and *DW* records. *SC* records allow *DW* record parameters to be assigned to groups of water rights satisfying specified criteria. *DW*, *DO*, and *SC* records are not used in the examples in this chapter. The default uniform distribution of monthly diversion and instream flow targets over all the days of each month is applied for all water rights. The simulation forecast period is automatically determined within *SIMD* and applied to each water right.

The *FR*, *FF*, *FV*, and *FQ* records apply to reservoir operations for flood control which are covered in Chapter 5. Example 7.2 incorporates these flood control records.

The information provided by the *RT*, *DC*, and *DF* records in a DCF file is used by *SIMD* to disaggregate monthly naturalized flows to sub-monthly (daily) time intervals using the options listed in Table 3.2 and to route flow changes through stream reaches using either the lag and attenuation method or *SIMD* adaptation of the Muskingum method. The lag and attenuation routing method is adopted for the examples. Routing parameters for normal flows are included in the DCF file for Example 7.1. Routing parameters for flood flows are added in Example 7.2.

Example 7.1 Conversion of the Monthly Model to a Daily Time Step

All of the *SIM* input files from the *Fundamentals Manual* example continue to be used in the daily simulation examples. The original FLO and EVA files are adopted without change. A daily *SIMD* model is created in Example 7.1 by modifying the DAT file and adding a DCF file. *SIMD* daily and aggregated monthly simulation results of Example 7.1 based on a daily computational time step are compared to the monthly *SIM* results in the *Fundamentals Manual*.

Input Data Added to the DAT File

The original *SIM* input DAT file is reproduced in Appendix A of the *Fundamentals Manual*. The only modifications to the DAT file in Example 7.1 are changing *ADJINC* in *JO* record field 8 from option 4 to option 7 and inserting the following *JT* and *JO* records following the *JO* record.

```
JT     0  -1  -1     0   0     0   0   0   2   2   2   0   0
JU     0     0.0     0.0   0   0   2   0   0   0    0
```

The recommended standard *JO* record *ADJINC* negative incremental flow options are option 4 or 6 for monthly and option 7 for daily simulations. Inclusion of all control points and water rights in the SUB output file is specified on the *JT* record. The *JU* record activates forecasting.

Input Data in the DCF File

The beginning of the DCF file for the example is reproduced as Table 7.2. The *RT* records in Table 7.2 activate the lag-attenuation routing method and provide routing parameters for the control points defining the upstream end of nine river reaches. Routing parameters are provided for all control points except WacoL and Hemp. The reach between control points WacoL and WacoG is judged to be too short to meaningfully capture routing effects occurring within a daily time step. Control point Hemp is the basin outlet and thus has no downstream routing reach. The lag time and attenuation time are provided on the *RT* records in units of days.

With the exception of the WacoL to WacoG reach noted in the preceding paragraph, control points in the example connect reaches of reasonably long travel time relative to a daily computational time step. However, for a river basin dataset with a large number of short reaches, some of the reaches can be omitted or aggregated for purposes of routing.

Options for disaggregating monthly naturalized flows to daily quantities are outlined in Table 3.2. The flow disaggregation methods adopted for each control point in this example are specified on the *DC* records shown in Table 7.2. The flow pattern option is set at the Hemp control point. The upstream application of the flow pattern option is selected for all control points upstream of Hemp. All upstream control points will use the flow pattern option and the *DF* record flow pattern at the control point location or first downstream *DF* record flow pattern is adopted. Three additional DC records are provided to override the flow pattern option at control points except PK and WacoL. Control point WacoL uses the interpolation method and therefore does not require additional information on its *DC* record. Interpolation is combined with a *DF* record flow pattern for disaggregating flows at control point PK. The High control point uses the flow pattern option, but adopts the *DF* record flow pattern at the upstream WacoG control point.

Although having daily flows at the same locations and covering the same periods as the monthly naturalized flows would be ideal, often only subsets of daily data are available. With the *DF* record flow patterns covering a shorter period of time than the overall hydrologic period-of-analysis, *SIMD* repeats the pattern as necessary. Daily flows at a location can serve as a pattern for disaggregating monthly flows at one or more other locations. The monthly naturalized flow volumes are always preserved with any of the WRAP disaggregation options.

Table 7.2
Beginning of the *SIMD* DCF File for Example 7.1

```
**  WRAP-SIMD Input File Ch7Exam1Daily.DCF
**  Example 7.1 in Chapter 7 of the Daily Simulation Manual
**  July 2012
**       1         2         3         4         5
**345678901234567890123456789012345678901234567890123456
**     !   !   !   !   !   !   !   !   !   !   !   !   !
RT    PK   1     2.8     2.0
RT  Whit   1     1.0     1.0
RT WacoG   1     0.7     1.0
RT  High   1     1.2     1.0
RTBelton   1     0.4     1.0
RTGeorge   1     0.6     1.0
RT Grang   1     0.6     1.0
RT Camer   1     0.9     1.0
RT Bryan   1     1.4     1.0
**     !   !   !   !   !   !   !   !   !   !   !   !   !
DC  Hemp      -4           1960       1    1969      12
DC    PK       3    Whit    1960       1    1969      12
DC WacoL       2
DC  High       4   WacoG    1960       1    1969      12
**
** Flows on DF records for the 3653 days from January 1960 through December 1969
** for control points Whit, Grang, Belton, WacoG, Camer, Bryan, and Hemp.
**       1         2         3         4         5         6         7         8
**34567890123456789012345678901234567890123456789012345678901234567890123456789O
**       !         !         !         !         !         !         !         !
DF  Whit        1960         1         4
   2327.00   1710.00   1401.00   1992.00  10576.00   7301.00   7793.00   6770.00
   5261.00   4333.00   2836.00   2702.00   2655.00   3328.00   3898.00   6249.00
   6141.00   3333.00   2430.00   2108.00   2004.00   1691.00   1265.00   1018.00
   1405.00   1246.00   1599.00   1762.00    562.00   1427.00   1197.00
DF  Whit        1960         2         4
   1208.00   1079.00   3524.00   2567.00   1839.00   3544.00   3075.00   2389.00
   2567.00   1315.00   1192.00    721.00    927.00    816.00   1054.00   1418.00
   1206.00    376.00    261.00   1563.00   1133.00    551.00   2091.00    560.00
    491.00    407.00    982.00   1038.00   1070.00
DF  Whit        1960         3         4
    644.00    823.00    552.00    708.00   1019.00    811.00   1069.00    822.00
    246.00    690.00    207.00    289.00    359.00    451.00    455.00    508.00
    372.00    689.00    638.00    423.00    616.00    966.00    448.00    501.00
    320.00    654.00    533.00    455.00   1163.00    683.00    561.00
DF  Whit        1960         4         4
    459.00    412.00    404.00    410.00    424.00    444.00    444.00    432.00
    428.00    429.00    413.00    379.00    414.00    126.00     82.00    495.00
   1020.00    860.00    564.00    928.00    298.00    198.00    137.00   1395.00
   2487.00   1341.00   9437.00   3778.00   4223.00   2644.00
DF  Whit        1960         5         4
   2269.00   1869.00   1304.00   4047.00   7023.00   1441.00    660.00   1338.00
   1778.00    806.00    835.00    193.00    105.00    165.00    568.00   1057.00
    664.00    412.00    185.00    820.00    222.00    498.00    747.00    473.00
    514.00    884.00    757.00    253.00    966.00    805.00    721.00
```

In the examples in this chapter, the hydrologic simulation period is 1940-1997, but daily flows are provided for only 1960-1969. The 1940-1949 naturalized monthly flow volumes starting in January 1940 are disaggregated to daily flows based on a ten year daily pattern starting in January 1960. The daily pattern reflected in the 1960-1969 daily flows are then applied to 1950-1959, 1960-1969, 1970-1999, and 1980-1989 monthly flows. The 1960-1967 daily flows are used in disaggregating 1990-1997 monthly naturalized flows to daily.

The 1960–1969 daily flows at seven of the eleven control points are provided on *DC* records in the DCF file. Control point PK as well as Whit use the flow pattern established by the flows at control point Whit. The daily pattern derived from the flows at control point WacoG are repeated at control point High. *SIMD* derives a daily flow pattern to disaggregate monthly flows at both control points George and Grang based on the daily flows at control point Grang.

The daily flows in the DCF file are in units of $(ft^3/s)\cdot day$, often called second-foot-day. Because of the daily pattern normalization, the units of the *DF* record data do not have to conform to the units of the monthly naturalized flow. Pattern normalization converts the *DF* record data to a dimensionless pattern in order to preserve the monthly naturalized flow volume units. More data may be provided on the *DF* records than is adopted for use by the *DC* records. For example, a very large daily dataset spanning several decades at many locations may be available. All of this information can be converted into *DF* records by the program *DAY* and placed in the DCF file. The user can then select any subset of years and locations in the *DC* records. *SIMD* reads the *DC* and *DF* records at the beginning of the simulation and stores the necessary pattern flows from the *DF* records in memory. This is done only once at the beginning of the simulation to minimize the time consuming process of reading a large data file.

Simulation Results

The simulation of the *Fundamentals Manual* covers the 696 months of the 1940-1997 hydrologic period-of-analysis. The daily simulations of this chapter step through the 21,185 days of 1940-1997 that includes 43 years with 365 days and 15 years with 366 days. *SIMD* and *TABLES* automatically assign February 29 days in leap years and 28 days in other years.

SIMD stores the simulation results in two output files with the filename extensions SUB and OUT. *TABLES* reads both of these files and organizes the simulation results. The flow and storage volumes and other quantities in the SUB file are for a daily time interval. *SIMD* performs the simulation with a daily computational time step, records the daily results in the SUB file, and then sums the daily amounts to monthly totals which are recorded in the OUT file. The SUB and OUT files have the same variables and same general format. The SUB file with daily records (lines of data) has 21,185/696=30.44 times as many sets of water right and control point output records as the OUT file comprised of monthly output records.

The beginning of the SUB file for the example is reproduced as Table 7.3. The beginning of the OUT file created with *SIM* from a monthly simulation is found in Appendix A of the *Fundamentals Manual*. The OUT file generated by *SIMD* with aggregated monthly results from a daily simulation for this example looks the same but the numbers are different. The summation of daily simulation results for each month does not necessarily yield the same monthly amounts as a simulation performed with a monthly computational time step.

Table 7.3

Beginning of the SUB File for Example 7.1

```
WRAP-SIMD (July 2012) SUB Output File
  WRAP-SIMD Input File Ch7Exam1Daily.DAT
  Example 7.1 in Chapter 7 of the Daily Simulation Manual
  July 2012
  1940    1  1997    12 21185    11    29     0
     0    31    28    31    30    31    30    31    31    30    31    30    31
IF   1      0.00      0.00      0.00      0.00      0.00      0.00      0.00         IF-1      9.86      0.00      0.00  0
IF   1      0.00      0.00      0.00      0.00      0.00      0.00      0.00         IF-2    328.77      0.00      0.00  0
1940 1     0.000   125.806     20.48 103991.29     37.57     37.57      0.00         WR-6WacoLake           44.03      0.00
1940 1     0.000    20.548     83.69 570240.00    104.24    242.19      0.00         WR-1      PK            7.19      0.00
1940 1     0.000   427.630     83.68 569950.31    137.94    137.94      0.00         WR-2      PK            0.00      0.00
1940 1     0.000     1.823      0.00      0.00      1.82    133.10      0.00        WR-14 Cameron            0.18      0.00
1940 1     0.000     5.565      0.00      0.00      5.56    349.35      0.00        WR-20   Bryan            0.28      0.00
1940 1     0.000     8.000      0.00      0.00      8.00    166.11      0.00        WR-22    Hemp            0.00      0.00
1940 1     0.000     5.210      0.00      0.00      5.21    484.34      0.00        WR-16WacoGage            0.00      0.00
1940 1     0.000     7.226      0.00      0.00      7.23    419.56      0.00        WR-17Highbank            0.00      0.00
1940 1     0.000    34.052      0.00      0.00     34.05    131.28      0.00        WR-13 Cameron           17.03      0.00
1940 1     0.000    72.968      0.00      0.00     72.97    340.50      0.00        WR-19   Bryan           47.43      0.00
1940 1    20.751   178.865      0.00      0.00    158.11    158.11      0.00        WR-21    Hemp            0.00      0.00
1940 1     0.000   173.529     37.16 457389.31      0.00      0.00      0.00         WR-8  Belton           78.09      0.00
1940 1     0.000   170.179     37.16 457219.12      0.00      0.00      0.00         WR-9  Belton           34.04      0.00
1940 1     0.000    53.752      4.39  37041.86      0.00      0.00      0.00        WR-10  George           25.80      0.00
1940 1     0.000    88.153     13.76  65398.09      0.00      0.00      0.00        WR-11 Granger           35.26      0.00
1940 1     0.000    37.742     57.96 627100.00     95.70    155.19      0.00         WR-3 Whitney           15.10      0.00
1940 1    14.855    14.855      0.00      0.00      0.00      0.00      0.00        WR-12 Cameron            0.00      0.00
1940 1     0.000    53.311      0.00      0.00     53.31    250.21      0.00        WR-18   Bryan           21.32      0.00
1940 1     0.000    43.613     28.25 191939.91      0.00      0.00      0.00         WR-7WacoLake           17.45      0.00
1940 1     0.000   184.701      0.00      0.00      0.00      0.00    184.70        WR-15 SystemC           64.65      0.00
1940 1    12.016    12.016      0.00      0.00      0.00      0.00      0.00        WR-23    Hemp            0.00      0.00
1940 1     0.000  1888.986      0.00      0.00      0.00      0.00   1888.99        WR-24 SystemH            0.00      0.00
1940 1     0.000     0.000     57.96 627100.00      0.00      0.00      0.00         WR-5  Refill            0.00      0.00
1940 1     0.000     0.000     83.55 567817.56      0.00      0.00      0.00        WR-25  Refill            0.00      0.00
1940 1     0.000     0.000     37.15 457029.12      0.00      0.00      0.00        WR-26  Refill            0.00      0.00
1940 1     0.000     0.000      4.39  37041.86      0.00      0.00      0.00        WR-27  Refill            0.00      0.00
1940 1     0.000     0.000     13.76  65398.09      0.00      0.00      0.00        WR-28  Refill            0.00      0.00
    PK     0.000   448.178     83.55 567817.56    242.19      0.00      0.00    242.19   2132.91     0.  130.   2133.      0.0
  Whit     0.000    37.742     57.96 627100.00     95.70      0.00      0.00    272.46    176.76     0.    0.      0.      0.0
 WacoL     0.000   169.419     28.25 191939.91     37.57      0.00      0.00     37.57      0.00     0.    0.      0.      0.0
 WacoG     0.000     5.210      0.00      0.00      5.21      0.00      0.00    555.72    512.94     0.    0.      0.      0.0
  High     0.000     7.226      0.00      0.00      7.23      0.00      0.00    606.85    586.92     0.    0.      0.      0.0
Belton     0.000   343.708     37.15 457029.12      0.00      0.00      0.00     32.55    222.58     0.    5.    190.      0.0
George     0.000    53.752      4.39  37041.86      0.00      0.00      0.00      9.05      9.05     0.    0.      0.      0.0
 Grang     0.000    88.153     13.76  65398.09      0.00      0.00     25.80     29.12     54.92     0.    0.      0.      0.0
 Camer    14.855   235.430      0.00      0.00     35.87      0.00     35.26    142.97    152.52     0.    0.      0.      9.9
 Bryan     0.000   131.844      0.00      0.00    131.84      0.00      0.00    349.52    218.60     0.    0.      0.      0.0
  Hemp    32.767  2087.866      0.00      0.00    166.11      0.00      0.00    494.88    328.77     0.    0.      0.    328.8
IF   1      0.00      0.00      0.00      0.00      0.00      0.00      0.00         IF-1      9.86      0.00      0.00  0
IF   1      0.00      0.00      0.00      0.00      0.00      0.00      0.00         IF-2    328.77      0.00      0.00  0
1940 1     0.000   125.806     20.48 103991.22     37.50     37.50      0.00         WR-6WacoLake           44.03      0.00
1940 1     0.000    20.548     83.42 567889.81    176.27    176.27      0.00         WR-1      PK            7.19      0.00
1940 1     0.000   427.630     83.39 567462.25      0.00      0.00      0.00         WR-2      PK            0.00      0.00
1940 1     0.000     1.823      0.00      0.00      1.82    292.20      0.00        WR-14 Cameron            0.18      0.00
1940 1     0.000     5.565      0.00      0.00      5.56    857.37      0.00        WR-20   Bryan            0.28      0.00
1940 1     0.000     8.000      0.00      0.00      8.00    330.68      0.00        WR-22    Hemp            0.00      0.00
1940 1     0.000     5.210      0.00      0.00      5.21    352.55      0.00        WR-16WacoGage            0.00      0.00
1940 1     0.000     7.226      0.00      0.00      7.23    398.12      0.00        WR-17Highbank            0.00      0.00
1940 1     0.000    34.052      0.00      0.00     34.05    290.37      0.00        WR-13 Cameron           17.03      0.00
1940 1     0.000    72.968      0.00      0.00     72.97    843.70      0.00        WR-19   Bryan           47.43      0.00
1940 1     0.000   178.865      0.00      0.00    178.86    322.68      0.00        WR-21    Hemp            0.00      0.00
1940 1     0.000   173.529     37.13 456841.47     23.00     23.00      0.00         WR-8  Belton           78.09      0.00
```

The *TABLES* input TIN file reproduced as Table 7.4 produces a *TABLES* output TOU file containing the tables presented as Tables 7.7 through 7.14. The frequency and reliability tables of Tables 7.7 through 7.14 are listed in Table 7.5. Summary statistics for monthly versus daily simulations are compared in Table 7.6.

Table 7.4
TABLES Input TIN File for the Example 7.1

```
**  TABLES Input File Ch7Exam1Daily.TIN
**
2FRE   1
2FRE   2
2FRE   3
**
6FRE   1
6FRE   2
6FRE   3
**
2FRE   4
6FRE   4
**
2FRE   8   0   2
IDEN           IF-1            IF-2
6FRE   8   0   2
IDEN           IF-1            IF-2
**
2REL   0   0   1
6REL   0   0   1
ENDF
```

Table 7.5
Listing of Frequency and Reliability Tables

	Monthly		Daily	
	Record	Table	Record	Table
flow frequency for naturalized, regulated, and unappropriated flows	2FRE	7.7	6FRE	7.8
reservoir storage frequency	2FRE	7.9	6FRE	7.10
frequency of instream flow shortages	2FRE	7.11	6FRE	7.12
water supply diversion reliability	2REL	7.13	6REL	7.14

Frequency and reliability tables are created from daily simulation results and aggregated monthly simulation results as outlined in Table 7.5. Tables 7.8, 7.10, and 7.12 were created by *TABLES* from the daily simulation results recorded by *SIMD* in the SUB file in accordance with 6FRE records in the TIN file of Table 7.4. The corresponding tables created with 2FRE records from the aggregated monthly *SIMD* simulation results in the OUT file are presented in Tables 7.7, 7.9, and 7.13. Water supply diversion reliabilities developed with 2REL and 6REL records are presented as Tables 7.13 and 7.14. These frequency and reliability tables created with

TABLES from daily SUB file and aggregated monthly OUT file *SIMD* simulation results may be compared with each other and with the corresponding tables in Appendix B of the *Fundamentals Manual* derived from the monthly computational time step *SIM* simulation. Several stream flow and reservoir storage volume statistics from *SIM* monthly, *SIMD* aggregated monthly, and *SIMD* daily simulation results are compared in Table 7.6.

Table 7.6
Comparison of Stream Flow and Storage Frequency Statistics from
Tables 7.7, 7.8, 7.9, and 7.10 and the *Fundamentals Manual*

	mean (cfs)	75% (cfs)	50% (cfs)	25% (cfs)
Naturalized Flows at Control Point Hemp (ac-ft/month and ac-ft/day)				
SIM monthly (*Fundamentals Manual*)	446,579	89,698	229,331	581,968
SIMD aggregated monthly (Table 7.7)	446,579	89,698	229,331	581,968
SIMD aggregated monthly (ac-ft/day)	14,682	2,949	7,540	19,133
SIMD daily simulation (Table 7.8)	14,672	2,043	5,357	15,501
Regulated Flows at Control Point Hemp (ac-ft/month and ac-ft/day)				
SIM monthly (*Fundamentals Manual*)	297,708	10,192	54,660	392,267
SIMD aggregated monthly (Table 7.7)	306,529	19,276	90,260	373,477
SIMD aggregated monthly (ac-ft/day)	10,077	633.7	2,967	12,279
SIMD daily simulation (Table 7.8)	10,077	328.8	740.4	9,029
Total Storage in the Six Reservoirs (acre-feet)				
SIM monthly (*Fundamentals Manual*)	1,408,150	1,079,430	1,491,909	1,809,009
SIMD aggregated monthly (Table 7.9)	1,232,450	798,826	1,273,266	1,680,615
SIMD daily simulation (Table 7.10)	1,233,978	803,778	1,274,124	1,685,224

The mean and the flows equaled or exceeded 75%, 50%, and 25% of the time at control point Hemp in Table 7.6 are taken from Tables 7.7 and 7.8 and Appendix B of the *Fundamentals Manual*. The median (50% exceedance frequency) flow is the monthly mean or daily mean flow rate that is equaled or exceeded during 50 percent of the 696 months or 50 percent of the 21,185 days of the 1940-1997 simulation. The statistics presented in Table 7.6 for simulated end-of-month and end-of-day total storage volume in the six reservoirs are from Appendix B of the *Fundamentals Manual* and Tables 7.9 and 7.10 of this manual.

The quantities in Table 7.6 for *SIM* monthly and *SIMD* aggregated monthly naturalized and regulated flow are in units of acre-feet/month. *SIMD* aggregated monthly volumes in acre-feet/day are also included in Table 7.6. The *SIMD* aggregated monthly volumes are converted to acre-feet/day by multiplying the quantities in acre-feet/month by 12/365. The *SIMD* daily naturalized and regulated flows in Tables 7.6 and 7.8 are in units of acre-feet/day.

The quantities for the monthly aggregation of *SIMD* daily naturalized flows in Table 7.6 are the same as the *SIM* naturalized flow quantities in Appendix B of the *Fundamentals Manual* as they should. The regulated and unappropriated flow statistics differ between Table 7.6 and the *Fundamentals Manual* which is also expected.

The aggregated monthly summations of regulated flows in the OUT file of a daily *SIMD* simulation differ from the monthly regulated flows in the OUT file of a *SIM* monthly simulation as a result of the daily flow patterns used in the daily time step simulation. The use of daily flow patterns creates fluctuations in water availability that is not represented in the monthly time step simulation. Additionally, the use of daily flow patterns creates the need to consider the effects of travel time for stream flow depletions, returns, and releases. The effects of travel time created by the use of daily flow patterns are captured in routing and forecasting.

Table 7.7
TABLES Output TOU File for Example 7.1
Flow Frequency Tables Based on Aggregated Monthly Flow Volumes

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	66123.6	137151.	0.0	0.0	0.0	284.0	2186.8	6883.0	12816.	18404.	30992.	64391.	166331.	1794495.
Whit	114921.1	204744.	0.0	0.0	1717.0	3425.4	6929.0	16626.0	28719.	46163.	65837.	131747.	280970.	2981239.
WacoL	29736.0	53194.	0.0	0.0	0.0	0.0	469.0	2712.0	5984.	9936.	15246.	34506.	80009.	526505.
WacoG	161860.3	266253.	0.0	1576.9	3433.8	6300.4	10363.6	24749.0	45705.	68642.	102411.	183578.	422755.	3376485.
High	194261.6	300104.	1251.0	3561.2	6377.8	8762.8	14725.6	31658.0	60614.	89483.	125100.	232892.	488252.	3599268.
Belton	42104.7	75480.	0.0	0.0	0.0	0.0	478.6	3360.0	7761.	12757.	22410.	47585.	113249.	629618.
George	4826.8	8471.	0.0	0.0	0.0	19.8	85.8	346.0	885.	1425.	2348.	5545.	14575.	75382.
Grang	15772.4	25225.	0.0	0.0	0.0	175.4	481.4	1805.0	3652.	5489.	8552.	19998.	45534.	212283.
Camer	109858.4	170466.	0.0	494.4	1249.0	2706.4	5440.0	15032.0	28988.	44799.	65294.	130473.	290433.	1403136.
Bryan	335663.4	483897.	0.0	6558.6	11161.7	17707.0	28172.8	60717.0	107622.	158629.	232671.	402271.	810073.	4704312.
Hemp	446578.5	588542.	1634.0	13817.1	17422.0	30122.4	44643.0	89698.0	157333.	229331.	306815.	581968.	1153505.	5723481.

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	44987.5	115889.	0.0	0.0	0.0	0.0	0.0	0.0	4087.	10253.	21639.	45153.	104200.	1782155.
Whit	73608.1	173752.	0.0	0.0	0.0	0.0	525.0	5107.3	16064.	27618.	40528.	72404.	168305.	2865974.
WacoL	21740.4	50800.	0.0	0.0	0.0	0.0	0.0	1.7	398.	1314.	4149.	16310.	68840.	525889.
WacoG	131237.1	225872.	0.0	4523.1	6438.4	12071.3	28281.9	40764.6	56245.	70887.	83660.	117831.	289620.	3265480.
High	161268.6	256830.	531.8	4741.7	7684.5	18272.4	34073.4	49597.9	67180.	81813.	99701.	156756.	373717.	3486854.
Belton	28399.9	58122.	0.0	0.0	0.0	0.0	0.0	468.5	4643.	9215.	14493.	29323.	70391.	504782.
George	3007.0	6967.	0.0	0.0	0.0	0.0	0.0	0.0	43.	117.	380.	2584.	9921.	65552.
Grang	11486.8	21158.	0.0	0.0	0.0	0.0	0.0	333.8	1793.	3447.	5964.	11640.	33787.	200098.
Camer	84683.9	143485.	0.0	197.6	305.8	1140.0	3533.0	15716.4	24803.	35225.	49729.	83343.	208922.	1392561.
Bryan	276139.8	413338.	896.2	6406.5	9714.9	27244.7	53537.7	80626.8	112192.	130957.	168347.	291529.	644343.	4412332.
Hemp	306529.2	520192.	0.0	6235.5	8453.3	9614.0	10191.8	19276.1	54573.	90260.	165460.	373477.	870712.	5308574.

Table 7.7 (continued)
Flow Frequency Tables Based on Aggregated Monthly Flow Volumes

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	14031.9	78479.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	747.	1278705.
Whit	34123.2	130702.	0.0	0.0	0.0	0.0	0.0	0.0	0.	319.	968.	4220.	75374.	1899107.
WacoL	16155.4	45143.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	6295.	51908.	525889.
WacoG	79612.2	197643.	0.0	0.0	0.0	0.0	0.0	2303.0	10141.	18532.	29932.	64100.	204510.	2540137.
High	107459.4	226482.	0.0	0.0	0.0	0.0	0.0	4804.9	16345.	28624.	47093.	102886.	278679.	2603692.
Belton	14997.7	53181.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	30372.	504782.
George	1930.9	6293.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	5923.	65552.
Grang	7243.1	19917.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	26.	25034.	200098.
Camer	66112.2	141187.	0.0	0.0	0.0	0.0	0.0	566.0	4008.	11192.	21861.	61275.	200206.	1387927.
Bryan	224385.3	420614.	0.0	0.0	0.0	0.0	0.0	9480.8	35267.	60855.	114179.	251585.	602073.	4351264.
Hemp	296866.2	520051.	0.0	0.0	0.0	0.0	0.0	9413.1	45294.	80611.	155466.	363285.	860652.	5298380.

Table 7.8
Flow Frequency Tables Based on Daily Flow Volumes

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL		STANDARD	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	2172.39	7436.5	0.00	0.00	0.00	0.89	15.57	91.10	226.0	386.1	638.4	1496.5	4727.9	355638.9
Whit	3775.55	10372.6	0.00	0.00	14.26	50.21	107.20	326.90	634.7	983.7	1505.2	3141.6	8701.3	381986.2
WacoL	976.93	1872.0	0.00	0.00	0.00	0.00	4.18	64.58	165.3	274.8	478.1	1046.4	2658.7	27762.4
WacoG	5317.66	12586.3	0.00	15.67	34.99	90.10	179.71	502.04	1008.9	1555.0	2347.7	4695.9	12571.2	374234.1
High	6382.16	14453.5	10.20	40.28	59.93	132.78	247.57	674.95	1295.0	1966.0	2917.9	5790.7	15275.5	398926.4
Belton	1383.28	3892.5	0.00	0.00	0.00	0.00	0.00	43.14	137.2	255.4	453.5	1091.8	3412.2	166329.9
George	158.58	534.3	0.00	0.00	0.00	0.17	1.46	7.39	18.3	31.6	52.5	129.3	370.1	28956.2
Grang	518.18	1636.5	0.00	0.00	0.00	1.97	7.95	36.96	81.4	129.4	200.2	459.0	1181.8	81543.6
Camer	3609.23	9005.6	0.00	3.51	11.78	34.38	78.15	286.63	609.5	974.9	1551.1	3398.0	8652.7	245584.4
Bryan	11027.70	23071.9	0.00	71.17	153.25	289.85	494.98	1322.87	2503.0	3745.0	5561.9	10893.0	26100.0	859923.3
Hemp	14671.63	27027.7	18.04	162.90	268.63	479.89	791.10	2042.99	3704.0	5357.0	7927.6	15501.3	36850.5	558560.6

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL		STANDARD	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	1477.99	6213.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	1140.3	3478.3	304229.1
Whit	2418.28	9040.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	185.8	787.4	1955.2	4695.5	369820.0
WacoL	714.25	1816.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	8.9	521.2	2317.6	27748.2
WacoG	4311.59	10895.0	0.00	0.00	0.00	0.00	135.04	836.77	1289.5	1725.9	2279.5	3461.3	8459.2	373769.7
High	5298.23	12813.0	0.00	0.00	0.00	18.65	261.63	1010.66	1569.0	2030.5	2591.6	4068.9	10937.7	398358.4
Belton	933.04	3148.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	55.4	432.4	2788.9	101638.8
George	98.79	449.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	2.0	233.2	17136.9
Grang	377.38	1325.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	10.9	251.5	1036.9	50838.6
Camer	2782.18	7865.0	0.00	3.80	9.86	9.86	9.86	91.10	451.2	810.6	1275.5	2352.3	6060.4	212380.3
Bryan	9072.14	20171.5	0.00	0.00	82.71	262.26	844.74	1864.82	2708.3	3411.9	4338.6	7467.5	19929.8	816525.6
Hemp	10070.22	24174.4	0.00	0.00	71.94	317.43	328.77	328.77	328.8	740.4	2674.6	9029.0	28406.4	509739.0

Table 7.8 (continued)
Flow Frequency Tables Based on Daily Flow Volumes

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	461.00	3857.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	131355.1
Whit	1121.06	5687.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1306.2	145089.2
WacoL	530.76	1665.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1649.2	27748.2
WacoG	2615.53	8684.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	367.8	1456.2	5877.3	217697.8
High	3530.41	10296.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	777.2	2429.5	8697.4	217475.5
Belton	492.73	2537.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	166.0	95633.9
George	63.44	369.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	94.3	16116.8
Grang	237.96	1221.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	617.0	50838.6
Camer	2172.01	7548.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	133.6	1233.0	5423.5	212370.4
Bryan	7371.82	20285.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1940.3	6369.7	19061.1	816525.6
Hemp	9753.07	24170.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	411.6	2345.9	8700.5	28077.6	509410.2

Table 7.9
Reservoir Storage Frequency Table Based on Aggregated Monthly Storage Volumes

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	291647.	202528.	0.	0.	0.	0.	0.	90296.	219301.	310187.	384275.	478774.	564732.	570240.
Whit	503841.	92185.	331870.	350554.	354024.	366437.	377710.	418145.	476102.	508688.	537386.	590909.	627100.	627100.
WacoL	159714.	42899.	0.	7069.	29425.	59311.	99086.	148642.	165995.	174946.	183361.	191920.	192100.	192100.
WacoG	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
High	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Belton	223547.	172183.	0.	0.	0.	0.	0.	39193.	148723.	239212.	300990.	388776.	457600.	457600.
George	17744.	14250.	0.	0.	0.	0.	0.	1080.	11653.	18509.	24072.	31952.	37100.	37100.
Grang	35955.	24935.	0.	0.	0.	0.	0.	10510.	29741.	40066.	48025.	62186.	65500.	65500.
Camer	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Bryan	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Hemp	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Total	1232450.	499618.	346352.	389883.	404948.	455626.	509652.	798826.	1079873.	1273266.	1435970.	1680615.	1898250.	1949640.

The storage frequency tables in Tables 7.9 and 7.10 are also taken from the *TABLES* output TOU file. The quantities in Table 7.9 are end-of-month storage contents in acre-feet. The frequencies in Table 7.9 are the percentage of the 696 months of the 1940-1997 *SIMD* simulation for which the storage volume at the end of the month equaled or exceeded the indicated volume. The quantities in Table 7.10 are end-of-day storage contents in acre-feet. The frequencies in Table 7.10 are the percentage of the 21,185 days of the simulation during which the storage content at the end of the day equaled or exceeded the indicated volume.

Table 7.10
Reservoir Storage Frequency Table Based on Daily Storage Volumes

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
PK	291246.	202515.	0.	0.	0.	0.	0.	86872.	221155.	307285.	380837.	479478.	564949.	570240.
Whit	505259.	91885.	331870.	349975.	353895.	366907.	378012.	419159.	479388.	508950.	540633.	592214.	627100.	627100.
WacoL	159878.	42759.	0.	6096.	27354.	57982.	98667.	148447.	166734.	175095.	183811.	192084.	192100.	192100.
WacoG	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
High	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Belton	224062.	172203.	0.	0.	0.	0.	0.	40427.	149817.	240703.	302169.	389662.	457600.	457600.
George	17675.	14168.	0.	0.	0.	0.	0.	1073.	11814.	18601.	23946.	31647.	37100.	37100.
Grang	35858.	24803.	0.	0.	0.	0.	0.	9979.	29734.	39855.	47720.	61532.	65500.	65500.
Camer	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Bryan	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Hemp	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Total	1233978.	499090.	346260.	390057.	402060.	454176.	510666.	803778.	1082113.	1274125.	1446066.	1685224.	1902540.	1949640.

Water rights IF-1 and IF-2 are instream flow requirements. The shortage statistics in Tables 7.11 and 7.12 for IF-1 and IF-2 were computed from the sum of the daily shortages during each of the 696 months recorded in the OUT file (Table 7.11) and the sum of the daily shortages in each of the 21,185 days recorded in the SUB file (Table 7.12). The quantities are in units of acre-feet/month in Table 7.11 and acre-feet/day in Table 7.12.

Table 7.11
Instream Flow Shortage Frequency Table Based on Aggregated Monthly Flows

FREQUENCY VERSUS INSTREAM FLOW SHORTAGES FOR SPECIFIED WATER RIGHTS

WATER RIGHT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH SHORTAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
IF-1	3.33	24.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	305.75
IF-2	337.01	1052.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.46	1049.55	10191.78

Table 7.12
Instream Flow Shortage Frequency Table Based on Daily Flows

FREQUENCY VERSUS INSTREAM FLOW SHORTAGES FOR SPECIFIED WATER RIGHTS

Daily Data from January 1940 through December 1997

WATER RIGHT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH SHORTAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
IF-1	0.11	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.86
IF-2	11.07	53.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	328.77

Shortages refer to regulated flows falling below the minimum instream flow targets at control points Camer and Hemp specified by water rights IF-1 and IF-2. The *SIM* monthly simulation in the *Fundamentals Manual* results in shortages in two months for IF-1 and no shortages for IF-2. The mean shortages for IF-1 and IF-2 for the *SIM* monthly simulation are 0.53 acre-feet/month and 0.00 as compared to mean shortages in Table 7.11 of 3.38 and 158.43 acre-feet/month. Thus, converting from a monthly to a daily computational time step results in an increase in instream flow shortages for this hypothetical example dataset.

The mean 1940-1997 instream flow shortage of 337.01 acre-feet/month for IF-2 in Table 7.11 is converted to 11.08 acre-feet/day by multiplying by (12/365) which is equal to the 11.07 acre-feet/day mean shortage in Table 7.12. The mean 1940-1997 instream flow shortage of 3.33 acre-feet/month for IF-1 in Table 7.11 is equivalent to 0.11 acre-feet/day. Thus, the 1940-1997 mean of the aggregated monthly shortages and the 1940-1997 mean of the daily shortages are the same as expected. Tables 7.11 and 7.12 indicate that instream flow shortages occur infrequently. However, the 10 percent exceedance frequency shortage for IF-2 is 1,050 acre-feet/month in Table 7.11 and zero in Table 7.12.

Table 7.13
Water Supply Diversion Reliabilities Based on Aggregated Monthly Volumes

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	++++++++ PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING ++++++++ 100%	95%	90%	75%	50%	25%	1%	------- PERCENTAGE OF YEARS WITH TARGET DIVERSION AMOUNT ------- 100%	98%	95%	90%	75%	50%
WR-6	60000.0	206.51	99.14	99.66	99.1	99.3	99.4	99.4	99.4	99.9	99.9	96.6	96.6	96.6	98.3	100.0	100.0
WR-1	9800.0	406.31	88.51	95.85	88.5	91.2	92.4	94.4	96.8	98.1	98.9	63.8	74.1	81.0	89.7	91.4	100.0
WR-2	245000.0	21173.37	84.34	91.36	84.3	85.6	86.5	87.8	91.7	94.1	98.3	63.8	63.8	67.2	75.9	89.7	91.4
WR-14	11300.0	1370.99	63.36	87.87	63.4	71.7	79.3	87.8	95.1	97.7	99.0	8.6	29.3	51.7	62.1	89.7	93.1
WR-20	34500.0	4148.33	55.60	87.98	55.6	64.4	75.9	85.5	96.1	99.0	99.4	3.4	20.7	46.6	56.9	82.8	100.0
WR-22	49600.0	5276.03	64.80	89.36	64.8	73.3	80.7	89.1	96.3	99.1	99.4	6.9	29.3	51.7	60.3	84.5	100.0
WR-16	32300.0	9258.27	33.33	71.34	33.3	43.0	53.2	68.5	83.8	93.8	98.4	0.0	5.2	8.6	19.0	51.7	81.0
WR-17	44800.0	12688.13	37.21	71.68	37.2	45.5	54.7	69.4	84.9	95.0	99.1	0.0	8.6	8.6	20.7	53.4	82.8
WR-13	18200.0	2986.66	48.99	83.59	49.0	57.2	66.7	77.4	88.9	95.1	98.0	3.4	10.3	25.9	50.0	75.9	93.1
WR-19	39000.0	5261.67	50.86	86.51	50.9	58.0	70.4	81.2	91.8	97.1	99.3	1.7	12.1	29.3	55.2	82.8	98.3
WR-21	95600.0	11530.61	57.04	87.94	57.0	65.5	73.1	83.8	92.2	97.6	99.4	3.4	17.2	37.9	58.6	82.8	100.0
WR-8	82760.0	11385.07	81.32	86.24	81.3	82.3	82.5	83.6	85.6	89.4	94.0	60.3	63.8	65.5	67.2	79.3	89.7
WR-9	97500.0	14611.46	80.60	85.01	80.6	81.5	81.9	82.3	84.3	86.5	90.4	60.3	62.1	65.5	65.5	79.3	86.2
WR-10	25610.0	4593.08	76.15	82.07	76.1	76.7	77.6	79.2	81.3	84.8	94.8	60.3	60.3	60.3	63.8	74.1	82.8
WR-11	42000.0	5550.01	81.61	86.79	81.6	82.6	83.6	84.3	86.8	89.4	96.1	62.1	62.1	62.1	69.0	79.3	87.9
WR-3	18000.0	2030.58	83.91	88.72	83.9	84.6	86.1	87.9	89.2	90.5	90.8	58.6	67.2	72.4	75.9	77.6	89.7
WR-12	92100.0	39908.86	39.80	56.67	39.8	51.3	57.8	68.2	78.4	89.7	97.4	0.0	0.0	1.7	8.6	17.2	62.1
WR-18	25400.0	2759.30	53.74	89.14	53.7	67.2	77.9	86.5	93.0	96.1	99.3	3.4	29.3	46.6	65.5	89.7	96.6
WR-7	20800.0	99.25	99.14	99.52	99.1	99.3	99.3	99.3	99.4	99.4	99.7	96.6	96.6	96.6	96.6	100.0	100.0
WR-15	88000.0	10456.84	83.33	88.12	83.3	84.2	84.8	85.6	88.4	90.5	95.7	62.1	62.1	67.2	70.7	81.0	91.4
WR-23	74500.0	17781.63	58.19	76.13	58.2	64.7	71.7	79.9	90.5	96.0	99.1	1.7	8.6	15.5	29.3	63.8	87.9
WR-24	899999.9	68361.54	87.21	92.40	87.2	87.9	88.2	89.4	93.2	96.1	99.1	65.5	65.5	74.1	79.3	89.7	91.4
Total	2106770.0	251844.50		88.05													

Table 7.14
Water Supply Diversion Reliabilities Based on Daily Volumes

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF DAYS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%
WR-6	60000.0	206.51	99.46	99.66	99.5	99.5	99.5	99.5	99.6	99.7	99.8	99.1	99.3	99.4	99.4	99.4	99.9	99.9
WR-1	9800.0	406.31	95.51	95.85	95.5	95.6	95.6	95.7	96.0	96.3	96.8	88.5	91.2	92.4	94.4	96.8	98.1	98.9
WR-2	244999.6	21173.37	89.63	91.36	89.6	89.7	89.7	90.0	90.7	92.0	95.4	84.3	85.6	86.5	87.8	91.7	94.1	98.3
WR-14	11300.0	1370.99	90.63	87.87	90.6	90.7	90.7	90.9	91.2	91.5	92.0	63.4	71.7	79.3	87.8	95.1	97.7	99.0
WR-20	34500.0	4148.33	90.00	87.98	90.0	90.1	90.2	90.4	90.9	91.2	91.5	55.6	64.4	75.9	85.5	96.1	99.0	99.4
WR-22	49600.0	5276.03	91.21	89.36	91.2	91.3	91.5	91.9	92.5	93.5	94.3	64.8	73.3	80.6	89.1	96.3	99.1	99.4
WR-16	32300.1	9258.28	77.73	71.34	77.7	77.8	78.0	78.3	78.9	79.4	79.8	33.3	43.0	53.2	68.5	83.8	93.8	98.4
WR-17	44800.1	12688.15	79.16	71.68	79.2	79.3	79.4	79.8	80.4	81.0	81.5	37.2	45.5	54.7	69.4	85.1	95.0	99.1
WR-13	18200.0	2986.66	83.58	83.59	83.6	83.8	83.9	84.3	84.7	85.1	85.4	49.0	57.2	66.5	77.4	88.9	95.1	98.0
WR-19	39000.0	5261.67	86.58	86.51	86.6	86.7	86.7	87.0	87.5	87.8	88.1	50.9	58.0	70.1	81.2	91.8	97.1	99.3
WR-21	95600.1	11530.61	86.67	87.94	86.7	86.9	87.1	87.8	88.9	89.9	91.1	57.0	65.5	73.4	83.8	92.2	97.6	99.4
WR-8	82760.1	11385.07	85.24	86.24	85.2	85.3	85.4	85.7	86.1	87.2	89.2	81.3	82.3	82.5	83.6	85.6	89.4	94.0
WR-9	97499.8	14611.46	84.41	85.01	84.4	84.4	84.5	84.5	84.7	84.9	85.3	80.6	81.5	81.9	82.3	84.3	86.5	90.4
WR-10	25610.0	4593.08	79.92	82.07	79.9	80.0	80.1	80.5	81.5	83.2	89.8	76.1	76.7	77.6	79.2	81.3	84.8	94.8
WR-11	42000.1	5550.01	85.55	86.79	85.5	85.6	85.6	85.9	86.6	88.2	91.1	81.6	82.6	83.6	84.3	86.8	89.4	96.1
WR-3	18000.0	2030.58	88.70	88.72	88.7	88.7	88.7	88.8	88.8	88.8	88.8	83.9	84.6	86.1	87.9	89.2	90.5	90.8
WR-12	92100.2	39908.84	69.75	56.67	69.7	70.2	70.7	72.6	76.0	81.2	89.3	39.8	51.3	57.8	68.2	78.4	89.7	97.4
WR-18	25400.0	2759.30	88.61	89.14	88.6	88.9	89.1	89.5	89.9	90.2	90.9	53.7	67.2	77.9	86.5	93.0	96.1	99.3
WR-7	20800.0	99.25	99.42	99.52	99.4	99.4	99.4	99.4	99.4	99.5	99.5	99.1	99.3	99.3	99.3	99.4	99.4	99.7
WR-15	87999.8	10456.84	87.84	88.12	87.8	87.9	87.9	88.1	88.4	88.8	90.0	83.3	84.2	84.8	85.6	88.4	90.5	95.7
WR-23	74500.0	17781.63	83.98	76.13	84.0	84.1	84.3	85.0	86.1	88.1	92.6	58.2	64.7	71.7	79.7	90.5	96.0	99.1
WR-24	900002.1	68361.53	91.26	92.40	91.3	91.4	91.4	91.8	92.6	93.7	95.3	87.2	87.9	88.2	89.4	93.2	96.1	99.1
Total	2106772.0	251844.53		88.05														

The reliability tables in Table 7.13 and Table 7.14 are the last two tables generated by the TIN file of Table 7.4. A volume reliability of 93.33% for the aggregated total of all diversion rights for the *Fundamentals Manual* simulation is reduced to 88.05% in Table 7.13. The volume reliabilities in Tables 7.13 and 7.14 are the same but the period reliabilities differ. The period reliabilities in Table 7.13 are the percentage of the 696 months of the simulation during which at least the specified percentage of the diversion target was supplied. The period reliabilities in Table 7.14 are the percentage of the 21,185 days of the simulation during which at least the specified percentage of the diversion target was supplied.

Routing Factor Array (RFA) SMM File Report

Routing of stream flow changes and incorporation of reverse routing in flow forecasting in the *SIMD* simulation are described in Chapter 3. Routing and reverse routing are based on a routing factor array (RFA). Examples 1, 2, 3, and 4 in Chapter 3 illustrate the concept of developing and applying a RFA. Routing factor arrays are automatically developed and applied within the *SIMD* simulation. The parameter RFASMM in *JT* record field 11 allows the RFA array to be recorded for user information as tables in the *SIMD* specific message file with the filename extension SMM. The RFA from the SMM file for Example 7.1 is reproduced as the following Table 7.15. The SMM file contains a table for each of the nine control points for which routing is applied. The table contains the factors used in the lag and attenuation routing computations for each routing reach from starting at the selected control point extending to the outlet. Routing factors that are used to rout within the current time step are listed in the Day 0 row. Future day routing factors are listed on the rows for Day 1 or greater.

Table 7.15
Routing Factor Array (RFA) from SMM File for Example 7.1

```
WRAP-SIMD (July 2012) SUBMONTHLY MESSAGE (SMM) FILE

--------------------------------------------------------------------------------
CONTROL POINT ID              PK      Whit     WacoG      High     Bryan    OUTLET
--------------------------------------------------------------------------------
DELIVERY FACTOR          1.00000   0.93900   0.99100   0.99000   0.98600   0.97500
CUMULATIVE DF            1.00000   0.93900   0.93055   0.92124   0.90835   0.88564
--------------------------------------------------------------------------------
TYPE OF ROUTING          LAG-ATT   LAG-ATT   LAG-ATT   LAG-ATT   LAG-ATT
LAG or MUSKINGUM K         2.800     1.000     0.700     1.200     1.400
ATT or MUSKINGUM X         2.000     1.000     1.000     1.000     1.000
--------------------------------------------------------------------------------
ROUTING        DAY 0   1.00000   0.00000   0.00000   0.00000   0.00000   0.00000
FACTOR             1   0.00000   0.09390   0.00000   0.00000   0.00000   0.00000
ARRAY (RFA)        2   0.00000   0.46950   0.09305   0.02764   0.00000   0.00000
                   3   0.00000   0.37560   0.46527   0.20267   0.02180   0.00000
                   4   0.00000   0.00000   0.37222   0.43298   0.16532   0.01275
                   5   0.00000   0.00000   0.00000   0.25795   0.38151   0.10521
                   6   0.00000   0.00000   0.00000   0.00000   0.28885   0.28766
                   7   0.00000   0.00000   0.00000   0.00000   0.05087   0.31777
                   8   0.00000   0.00000   0.00000   0.00000   0.00000   0.14241
                   9   0.00000   0.00000   0.00000   0.00000   0.00000   0.01984
--------------------------------------------------------------------------------

------------------------------------------------------------------------
CONTROL POINT ID            Whit     WacoG      High     Bryan    OUTLET
------------------------------------------------------------------------
DELIVERY FACTOR          1.00000   0.99100   0.99000   0.98600   0.97500
CUMULATIVE DF            1.00000   0.99100   0.98109   0.96735   0.94317
------------------------------------------------------------------------
TYPE OF ROUTING          LAG-ATT   LAG-ATT   LAG-ATT   LAG-ATT
LAG or MUSKINGUM K         1.000     0.700     1.200     1.400
ATT or MUSKINGUM X         1.000     1.000     1.000     1.000
------------------------------------------------------------------------
ROUTING        DAY 0   1.00000   0.00000   0.00000   0.00000   0.00000
FACTOR             1   0.00000   0.99100   0.29433   0.00000   0.00000
ARRAY (RFA)        2   0.00000   0.00000   0.68676   0.23217   0.00000
                   3   0.00000   0.00000   0.00000   0.59976   0.13582
                   4   0.00000   0.00000   0.00000   0.13543   0.44140
                   5   0.00000   0.00000   0.00000   0.00000   0.31313
                   6   0.00000   0.00000   0.00000   0.00000   0.05282
------------------------------------------------------------------------

--------------------------------------------------------------
CONTROL POINT ID           WacoG      High     Bryan    OUTLET
--------------------------------------------------------------
DELIVERY FACTOR          1.00000   0.99000   0.98600   0.97500
CUMULATIVE DF            1.00000   0.99000   0.97614   0.95174
--------------------------------------------------------------
TYPE OF ROUTING          LAG-ATT   LAG-ATT   LAG-ATT
LAG or MUSKINGUM K         0.700     1.200     1.400
ATT or MUSKINGUM X         1.000     1.000     1.000
--------------------------------------------------------------
ROUTING        DAY 0   1.00000   0.29700   0.00000   0.00000
FACTOR             1   0.00000   0.69300   0.23427   0.00000
ARRAY (RFA)        2   0.00000   0.00000   0.60521   0.13705
                   3   0.00000   0.00000   0.13666   0.44541
                   4   0.00000   0.00000   0.00000   0.31598
                   5   0.00000   0.00000   0.00000   0.05330
--------------------------------------------------------------
```

Table 7.15 (continued)
Routing Factor Array (RFA) from SMM File for Example 7.1

CONTROL POINT ID		High	Bryan	OUTLET
DELIVERY FACTOR		1.00000	0.98600	0.97500
CUMULATIVE DF		1.00000	0.98600	0.96135
TYPE OF ROUTING		LAG-ATT	LAG-ATT	
LAG or MUSKINGUM K		1.200	1.400	
ATT or MUSKINGUM X		1.000	1.000	
ROUTING	DAY 0	1.00000	0.00000	0.00000
FACTOR	1	0.00000	0.78880	0.00000
ARRAY (RFA)	2	0.00000	0.19720	0.46145
	3	0.00000	0.00000	0.42299
	4	0.00000	0.00000	0.07691

CONTROL POINT ID		Belton	Camer	Bryan	OUTLET
DELIVERY FACTOR		1.00000	0.97200	0.96400	0.97500
CUMULATIVE DF		1.00000	0.97200	0.93701	0.91358
TYPE OF ROUTING		LAG-ATT	LAG-ATT	LAG-ATT	
LAG or MUSKINGUM K		0.400	0.900	1.400	
ATT or MUSKINGUM X		1.000	1.000	1.000	
ROUTING	DAY 0	1.00000	0.58320	0.05622	0.00000
FACTOR	1	0.00000	0.38880	0.54346	0.03289
ARRAY (RFA)	2	0.00000	0.00000	0.33732	0.33985
	3	0.00000	0.00000	0.00000	0.40929
	4	0.00000	0.00000	0.00000	0.13156

CONTROL POINT ID		George	Grang	Camer	Bryan	OUTLET
DELIVERY FACTOR		1.00000	0.99200	0.98500	0.96400	0.97500
CUMULATIVE DF		1.00000	0.99200	0.97712	0.94194	0.91840
TYPE OF ROUTING		LAG-ATT	LAG-ATT	LAG-ATT	LAG-ATT	
LAG or MUSKINGUM K		0.600	0.600	0.900	1.400	
ATT or MUSKINGUM X		1.000	1.000	1.000	1.000	
ROUTING	DAY 0	1.00000	0.39680	0.15634	0.01507	0.00000
FACTOR	1	0.00000	0.59520	0.46902	0.18085	0.00000
ARRAY (RFA)	2	0.00000	0.00000	0.35176	0.44083	0.12049
	3	0.00000	0.00000	0.00000	0.30519	0.32842
	4	0.00000	0.00000	0.00000	0.00000	0.35046
	5	0.00000	0.00000	0.00000	0.00000	0.11902

Table 7.15 (continued)
Routing Factor Array (RFA) from SMM File for Example 7.1

```
------------------------------------------------------------
CONTROL POINT ID          Grang     Camer     Bryan    OUTLET
------------------------------------------------------------
DELIVERY FACTOR         1.00000   0.98500   0.96400   0.97500
CUMULATIVE DF           1.00000   0.98500   0.94954   0.92580
------------------------------------------------------------
TYPE OF ROUTING         LAG-ATT   LAG-ATT   LAG-ATT
LAG or MUSKINGUM K        0.600     0.900     1.400
ATT or MUSKINGUM X        1.000     1.000     1.000
------------------------------------------------------------
ROUTING         DAY 0   1.00000   0.39400   0.03798   0.00000
FACTOR              1   0.00000   0.59100   0.39881   0.02222
ARRAY (RFA)         2   0.00000   0.00000   0.51275   0.24811
                    3   0.00000   0.00000   0.00000   0.45549
                    4   0.00000   0.00000   0.00000   0.19997
------------------------------------------------------------

--------------------------------------------------
CONTROL POINT ID          Camer     Bryan    OUTLET
--------------------------------------------------
DELIVERY FACTOR         1.00000   0.96400   0.97500
CUMULATIVE DF           1.00000   0.96400   0.93990
--------------------------------------------------
TYPE OF ROUTING         LAG-ATT   LAG-ATT
LAG or MUSKINGUM K        0.900     1.400
ATT or MUSKINGUM X        1.000     1.000
--------------------------------------------------
ROUTING         DAY 0   1.00000   0.09640   0.00000
FACTOR              1   0.00000   0.86760   0.05639
ARRAY (RFA)         2   0.00000   0.00000   0.54514
                    3   0.00000   0.00000   0.33836
--------------------------------------------------

----------------------------------------
CONTROL POINT ID          Bryan    OUTLET
----------------------------------------
DELIVERY FACTOR         1.00000   0.97500
CUMULATIVE DF           1.00000   0.97500
----------------------------------------
TYPE OF ROUTING         LAG-ATT
LAG or MUSKINGUM K        1.400
ATT or MUSKINGUM X        1.000
----------------------------------------
ROUTING         DAY 0   1.00000   0.00000
FACTOR              1   0.00000   0.58500
ARRAY (RFA)         2   0.00000   0.39000
----------------------------------------
```

Disaggregation Parameter SMM File Report

The *DC* records for Example 7.1 are shown in Table 7.2. The first *DC* record in the DCF file is for the Hemp control point. The *DF* record flow pattern option is applied at the Hemp control point. The use of a negative value for field 3 DFMETHOD initiates a process for automatically assigning DFMETHOD to all control points upstream of control point Hemp. The automatic assignment process is described in Chapter 3 and Appendix A. Subsequent *DC* record override any parameters set by a previous *DC* record.

The use of the automatic upstream assignment of routing parameters with a negative value of DFMETHOD allows potentially all control points in the simulation to be assigned disaggregation parameters with a single *DC* record. The parameter DCSMM in JT record field 10 allows the optional output of all disaggregation parameters to the SIMD SMM file. The optional DCSMM output report is created in *DC* record format. An additional field is added to the end of the report that indicates is the disaggregation parameters were assigned automatically. The value of parameter DCSMM controls which control points are included in the report.

The disaggregation parameter report for Example 7.1 is reproduced as the following Table 7.16. The SMM file report contains a row for each of the control points in the example. All control points in the example are automatically assigned the DF record flow pattern option 4 method of disaggregation according to the first DC record in the DCF file. However, the subsequent DC records for the PK, WacoL, and High control points override the automatic assignment option of the first DC record. Therefore, the PF, WacoL, and High control points in Table 7.16 are indicated as not having automatic disaggregation parameter assignment.

Table 7.16
Disaggregation Parameter Report from SMM File for Example 7.1

DISAGGREGATION PARAMETERS PER CONTROL POINT in DC RECORD FORMAT

CD	DCID	DFMETH	DFID	BEGYR	BEGMT	ENDYR	ENDMT	LAG	X	M	A	Parameters Assigned by Automatic DFMETHOD
DC	PK	3	Whit	1960	1	1969	12	0	1.00	1.00	0.0	NO
DC	Whit	4	Whit	1960	1	1969	12	0	1.00	1.00	0.0	YES
DC	WacoL	2		1940	1	1997	12	0	1.00	1.00	0.0	NO
DC	WacoG	4	WacoG	1960	1	1969	12	0	1.00	1.00	0.0	YES
DC	High	4	WacoG	1960	1	1969	12	0	1.00	1.00	0.0	NO
DC	Belton	4	Belton	1960	1	1969	12	0	1.00	1.00	0.0	YES
DC	George	4	Grang	1960	1	1969	12	0	1.00	1.00	0.0	YES
DC	Grang	4	Grang	1960	1	1969	12	0	1.00	1.00	0.0	YES
DC	Camer	4	Camer	1960	1	1969	12	0	1.00	1.00	0.0	YES
DC	Bryan	4	Bryan	1960	1	1969	12	0	1.00	1.00	0.0	YES
DC	Hemp	4	Hemp	1960	1	1969	12	0	1.00	1.00	0.0	YES

Water Right Availability Forecast Period Limit SMM File Report

Example 7.1 uses the default option for *JU* record field 9 to automatically set the availability forecast period limits for all water rights. No *DW* records are used in Example 7.1 to override the *JU* record defaults. The application of the availability forecast period limit within the forecasting methodology is described in Chapter 3.

The availability forecast period limit report for Example 7.1 is reproduced as the following Table 7.17. The SMM file report contains row for each water right in the example. All water rights in the example are automatically assigned an availability forecast period limit according to the default method based on the routing travel time to the basin outlet. Instream flow rights do not use forecast values of water availability and therefore are not assigned an availability forecast period limit.

Table 7.17
Water Right Availability Forecast Period Limit Report from SMM File for Example 7.1

Availability Forecast Periods per Water Right

WATER RIGHT ID	APERIOD FUTURE DAYS	WR TYPE	PRIORITY	CP	USE	DIVERSION	HYDRO POWER	PRIMARY ID	RESERVOIR TOTAL	WR GROUP
IF-1	0	1	0	Camer	NDAYS	3600.0	0.0		0.0	IF#IF*IF
IF-2	0	1	0	Hemp	NDAYS	120000.0	0.0		0.0	IF#IF*IF
WR-1	9	1	193804	PK	MUN1	9800.0	0.0	PK	570240.0	PK
WR-2	9	1	193804	PK	IND1	245000.0	0.0	PK	570240.0	PK
WR-3	6	1	198208	Whit	MUN1	18000.0	0.0	Whit	627100.0	Whitney
WR-4	6	-3	888888	Whit	POWER	36000.0	0.0		0.0	Whit HP
WR-5	6	1	999999	Whit		0.0	0.0	Whit	627100.0	Refill
WR-6	5	1	192901	WacoL	MUN1	60000.0	0.0	WacoL	104100.0	WacoLake
WR-7	5	1	198609	WacoL	MUN1	20800.0	0.0	WacoL	192100.0	WacoLake
WR-8	4	1	196312	Belton	MUN1	82760.0	0.0	Belton	457600.0	Belton
WR-9	4	1	196312	Belton	IND1	97500.0	0.0	Belton	457600.0	Belton
WR-10	5	1	196802	George	MUN2	25610.0	0.0	George	37100.0	George
WR-11	4	1	196802	Grang	MUN2	42000.0	0.0	Grang	65500.0	Granger
WR-12	3	1	198211	Camer	IRR2	0.0	92100.0		0.0	Cameron
WR-13	3	1	196105	Camer	IND2	18200.0	0.0		0.0	Cameron
WR-14	3	1	194510	Camer	IRR2	0.0	11300.0		0.0	Cameron
WR-15	3	2	200601	Camer	MUN2	88000.0	0.0		0.0	SystemC
WR-16	5	1	194607	WacoG	IRR2	0.0	32300.0		0.0	WacoGage
WR-17	4	1	195903	High	IRR2	0.0	44800.0		0.0	Highbank
WR-18	2	1	198211	Bryan	MUN2	25400.0	0.0		0.0	Bryan
WR-19	2	1	196105	Bryan	IND2	39000.0	0.0		0.0	Bryan
WR-20	2	1	194510	Bryan	IRR2	0.0	34500.0		0.0	Bryan
WR-22	0	1	194510	Hemp	IRR2	0.0	49600.0		0.0	Hemp
WR-21	0	1	196105	Hemp	IND2	95600.0	0.0		0.0	Hemp
WR-23	0	1	200601	Hemp	IRR2	0.0	74500.0		0.0	Hemp
WR-24	0	2	200601	Hemp	MUN2	900000.0	0.0		0.0	SystemH
WR-25	9	1	999999	PK		0.0	0.0	PK	570240.0	Refill
WR-26	4	1	999999	Belton		0.0	0.0	Belton	457600.0	Refill
WR-27	5	1	999999	George		0.0	0.0	George	37100.0	Refill
WR-28	4	1	999999	Grang		0.0	0.0	Grang	65500.0	Refill

<u>Example 7.2 Modeling Flood Control Reservoir Operations</u>

The hypothetical example presented in the *Fundamentals Manual* and expanded here was created by extracting selected hydrology and reservoir data from the TCEQ WAM System dataset for the Brazos River Basin and adding other fabricated water rights data to develop a realistic though inaccurate simplified example which is illustrative but still hypothetical. The *Fundamentals Manual* example was converted from a monthly to daily time step in Example 7.1 and is further expanded here to include flood control. Example 7.2 consists of three parts:

- The *SIMD* input file of Example 7.1 is expanded to include flood control operations, and a *SIMD* simulation is performed. The resulting 1940-1997 sequences of daily stream flows and reservoir storage contents are plotted using HEC-DSSVue.
- The *TABLES* 7FFA record routine is used to perform flood frequency analyses of the *SIMD* simulation results.
- The HEC-SSP Statistical Software Package is used to perform flood frequency analyses of selected SIMD simulation results.

The system described in the *Fundamentals Manual* consists of eleven control points, six reservoirs, and 30 water rights. The schematic of the river/reservoir system is reproduced as Figure 7.1. This flood control example uses the input files of the original monthly example from the *Fundamentals Manual* along with daily time step data introduced in Example 7.1 plus additional data added here to simulate flood control operations. Operation of the five reservoirs for flood control is based on information presented in Tables 7.18 and 7.19 that is entered on *FR* and *FF* records in the *SIMD* input DAT file.

The 28 *WR* record and two *IF* record water rights in the original example from the *Fundamentals Manual* remain unchanged in Examples 7.1 and 7.2. The conservation pools of the six reservoirs continue to be operated in Example 7.2 the same as in Example 7.1. However, in Example 7.1, without *FR* record flood control storage, no water is stored above the top of conservation pool storage capacities defined by the *WS* records. Whenever a reservoir is full to conservation pool capacity, inflows pass through the reservoir instantaneously without storage.

<u>*Flood Control Operating Rules*</u>

In this example, five of the six reservoirs include designated flood control pools modeled in *SIMD* as controlled flood control storage. A system consisting of Belton, Granger, Georgetown, Whitney, and Waco Reservoirs is operated to control flood flows at the WacoG, Bryan, Hemp, and Camer control points as well as at the dam sites. These selected flood index locations represent the river system. Flood control pools are defined in Table 7.18. Flood control operations for the five-reservoir system are based on the maximum allowable flood flow levels listed in Table 7.18 and maximum flood pool releases listed in Table 7.19.

The storage volume versus surface area tables (*SV* and *SA* records) used by *SIMD* in evaporation computations are extended in this example to cover the flood control pools of the five reservoirs. The storage volume versus elevation table (*PV* and *PE* records) used in the Whitney hydropower computations is likewise extended in the DAT file.

Table 7.18
Flood Control Reservoir Operations Criteria on *FR* Records

Reservoir	Top of Conservation Pool (acre-feet)	Maximum Release Rate from Flood Control Pool: Instantaneous (ft^3/s)	*FR* Field 8 (ac-ft/day)	*FR* Record Levels Defining Flood Pool: Field 9 Top of FC (acre-feet)	Field 10 *FV/FQ* (acre-feet)	Field 11 Bottom of FC (acre-feet)
Possum Kingdom	570,240	not used	not used	665,540	570,240	570,240
Whitney	627,100	25,000	49,600	2,000,000	not used	627,100
Waco	192,100	20,000	39,700	726,400	not used	192,100
Belton	457,600	10,000	19,800	1,091,320	not used	457,600
Georgetown	37,100	4,000	7,930	130,800	not used	37,100
Granger	65,500	10,000	19,800	244,200	not used	65,500

Table 7.19
Flood Control Operating Criteria on *FF* Records

Control Point	Flood Flow Limit (ft^3/s)	(acre-feet/day)	(ac-ft/year)
WacoG	50,000	99,170	36,200,000
Bryan	60,000	119,010	43,440,000
Hemp	60,000	119,010	43,440,000
Camer	10,000	39,670	7,240,000

Possum Kingdom Reservoir has no controlled flood control storage. Surcharge storage above the top of conservation pool in Possum Kingdom Reservoir is modeled as a storage versus outflow table entered on *FV* and *FQ* records. A priority of 920000 is assigned to the *FV/FQ* record based flood release computations so that these computations will be made before the Whitney Reservoir storage computations which are controlled by a priority number of 930000.

Operation of Whitney, Waco, Belton, Granger, and Georgetown Reservoirs for flood control is based on flow levels at gaging stations at the WacoG, Bryan, Hemp, and Camer control points and in the river just downstream of the dams. The flood control pools defined in Table 7.18 are emptied as quickly as possible without contributing to stream flows exceeding the limits specified in Table 7.19. Maximum non-damaging flow rates in acre-feet/year are provided on *FF* records, and disaggregated to monthly volumes based on sets of 12 coefficients provided on *UC* records. In this example, maximum allowable flows are constant over the year as defined by a *UC* record connected to the *FF* records with the identifier FFLOW. Other target setting options activated by *TO, SO, TS, CV, FS,* and *DI* records may be applied to *FF* record maximum non-damaging flood flows in the same manner as *WR* record diversion targets and *IF* record instream flow targets. However, these options are not applied in this example.

Maximum release rates from the flood control pools are shown in Table 7.17 and entered in *FR* record field 7. These *FR* record maximum limits on releases from the flood control pool are equivalent to *FF* record maximum stream flow rates but are applied at the individual dam in the current day only without consideration of future forecasted flows.

Flow forecasting with reverse routing is applied by *SIMD* in making storage and release decisions. The option of allowing the forecast period to be automatically determined by *SIMD* is adopted. Lag and attenuation routing parameters are provided on *RT* Records.

The default *FRMETH* option 1 is selected in *JU* record field 6. In the *SIMD* simulation computations, changes in river flows caused by flood control operations in preceding time steps are placed at the beginning of the priority sequence. Effects of operation of each flood control reservoir on flood control operations of the other reservoirs is typically more accurately modeled by circumventing the priority system in this manner with *FRMETH* option 1. However, flood control storage and releases also affect flows available to *WR* record water supply rights.

Priority numbers of 910000 and 930000 are entered on the *FR* records for each of the five flood control reservoirs, making *FR* record flood control operations junior in the simulation computational sequence to all *WR* and *IF* record water rights. *FR* record fields 11 and 12 are blank, activating defaults of 1.0 and 0.0 for the factors M and A in Equation 5.4. Thus, multiple-reservoir release decisions are based on balancing the flood control storage contents as a percent of capacity in each of the five reservoirs. The order in which the *FR* records are placed in the DAT file also affects simulation results. The reservoir with *FR* record listed first is considered first if the Eq. 5.4 rank index is the same for all reservoirs in a particular day. An example of this situation is a day in which all reservoirs are at top of conservation pool (bottom of flood control pool) at the beginning of the day. The order of the reservoirs in the simulation computations may significantly affect the allocation of flood waters between the different flood control pools.

In *SIM* and *SIMD*, if a reservoir has no flood control pool, outflow equals inflow during periods in which the conservation storage capacity is full. With the reservoir filled to the top of conservation pool, inflows pass through the reservoir over the spillway as spills. In *SIMD*, if a reservoir has a flood control pool, outflow equals inflow during periods in which the flood control storage capacity is full. Spills through the spillway are assumed to occur instantaneously. In the real world, temporary surcharge storage can occur above the elevation of the designated top of flood control pool or above the top of conservation pool elevation if there is no flood control pool. *FV* and *FQ* records allow spills from surcharge storage to be modeled in *SIMD*. Surcharge storage above the top of conservation pool in Possum Kingdom is modeled using *FV* and *FQ* records. However, in this example, for the five reservoirs with controlled flood control pools, the model is simplified by assuming inflows are passed through the reservoir instantaneously any time the flood control pool is full to capacity with flood waters. *FV* and *FQ* records are not applied to model surcharge storage above the top of controlled flood control pools. Thus, in the simulation results, storage contents will never exceed the storage capacity at top of flood control pool.

<u>SIMD and TABLES Input and Output Files</u>

The complete *SIMD* input dataset for this example consists of DAT, DCF, FLO, and EVA files. The hydrology (FLO, EVA) files from the example in the *Fundamentals Manual* are used without revision in this example as well as the other examples in Chapters 2, 4, and 7.

The *SIMD* input DAT file is reproduced as Table 7.20. The DAT file includes all of the original records from the example in the *Fundamentals Manual*. *ADJINC* was changed to 7, and *JT* and *JU* records were added in Example 7.1. *FR* records for six reservoirs and *FF* records for four control points are added to simulate reservoir operations for flood control. *FV*/*FQ* records are added for PK. The *SV*, *SA*, *PV*, and *PE* records are extended to cover the flood control pools.

Table 7.20
SIMD Input DAT File for Flood Control Example 7.2

```
T1  WRAP-SIMD Input File Ch7Exam2Daily.DAT
T2  Example 7.2 in Chapter 7 of the Daily Simulation Manual
**
**       1         2         3         4         5         6         7         8         9        10
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
**-----!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!
**
JD    58    1940              -1                       7                      20
JO     2
JT        -1                           2
JU                         1   1   2
**
**  Water Use Coefficient (UC) Records
**
UC  IND1   0.054   0.060   0.070   0.083   0.094   0.105   0.113   0.106   0.096   0.083   0.072   0.062
UC  IND2   0.058   0.077   0.087   0.097   0.107   0.124   0.128   0.124   0.078   0.041   0.038   0.041
UC  IRR1   0.005   0.007   0.017   0.033   0.092   0.163   0.267   0.235   0.117   0.044   0.014   0.007
UC  IRR2   0.005   0.008   0.018   0.032   0.075   0.189   0.304   0.253   0.079   0.022   0.008   0.007
UC  MUN1   0.065   0.063   0.068   0.072   0.085   0.093   0.118   0.114   0.095   0.087   0.071   0.069
UC  MUN2   0.065   0.063   0.066   0.069   0.082   0.105   0.111   0.106   0.100   0.089   0.074   0.069
UC POWER   2250.   2250.   2250.   2250.   2250.   3000.   6000.   6000.   3000.   2250.   2250.   2250.
**
**  Control Point (CP) Records !-------!-------!-------!-------!-------!
**
CP    PK    Whit                                              0.061
CP  Whit   WacoG                                              0.009
CP WacoL   WacoG                                              0.000
CP WacoG    High                                   none       0.010
CP  High   Bryan                                   none       0.014
CPBelton   Camer                                              0.028
CPGeorge   Grang                                              0.008
CP Grang   Camer                                              0.015
CP Camer   Bryan                                   none       0.036
CP Bryan    Hemp                                   none       0.025
CP  Hemp                                           none
**
** Water Right (WR and IF) Records and Reservoir Storage (WS) Records
**
** Instream Flow Requirements at Cameron and Hempstead Gages  *!*******!*******!*******!
**
IF Camer   3600.   NDAYS       0               IF-1
IF  Hemp 120000.   NDAYS       0               IF-2
**
** Possum Kingdom Lake at Control Point PK  ***!*******!*******!*******!*******!*******!
**
WR    PK   9800.    MUN1  193804       2    0.35              WR-1            PK
WS    PK 570240.
WR    PK 245000.    IND1  193804                              WR-2            PK
WS    PK 570240.
**
** Whitney Lake at CP Whit     !*******!*******!*******!*******!*******!*******!*******!
**
WR  Whit  18000.    MUN1  198208       2    0.40              WR-3            Whitney
WS  Whit 627100.                        379000.
WR  Whit  36000.   POWER  777777   6   2                      WR-4            Whit HP
WS  Whit 627100.                        379000.
```

Table 7.20 (Continued)
SIMD Input DAT File for Flood Control Example 7.2

```
HP  0.86    440.
WR  Whit                 888888                                   WR-5            Refill
WS  Whit 627100.                        379000.
**
** Waco Lake at CP WacoL  *****!*******!*******!*******!*******!*******!*******!*******!
**
WR WacoL  60000.    MUN1  192901       2    0.35                  WR-6            WacoLake
WS WacoL 104100.
WR WacoL  20800.    MUN1  198609       2    0.40                  WR-7            WacoLake
WS WacoL 192100.
**
**  Belton Lake at CP Belton  *!*******!*******!*******!*******!*******!*******!*******!
**
WRBelton  82760.    MUN1  196312       2    0.45                  WR-8            Belton
WSBelton 457600.
WRBelton  97500.    IND1  196312       2    0.20                  WR-9            Belton
WSBelton 457600.
**
**  Georgetown Lake at CP George  *****!*******!*******!*******!*******!*******!*******!
**
WRGeorge  25610.    MUN2  196802       0    0.48                  WR-10           George
WSGeorge  37100.
**
**  Granger Lake at CP Grang  *!*******!*******!*******!*******!*******!*******!*******!
**
WR Grang  42000.    MUN2  196802       0    0.40                  WR-11           Granger
WS Grang  65500.
**
**  Cameron Gage - Run-of-River Diversion Rights  *****!*******!*******!*******!*******!
**
WR Camer  92100.    IRR2  198211       2    0.35                  WR-12           Cameron
WR Camer  18200.    IND2  196105       2    0.50                  WR-13           Cameron
WR Camer  11300.    IRR2  194510       2    0.10                  WR-14           Cameron
**
**  Cameron Gage - Multiple-Reservoir System Diversion Right  *!*******!*******!*******!
**
WR Camer  88000.    MUN2  200601   2   2    0.35                  WR-15           SystemC
WSBelton 457600.
WSGeorge  37100.
WS Grang  65500.
**
**  Waco Gage - Run-of-River Diversion Right  **!*******!*******!*******!*******!*******!
**
WR WacoG  32300.    IRR2  194607                                  WR-16           WacoGage
**
**  Highbank Gage - Run-of-River Diversion Right  *****!*******!*******!*******!*******!
**
WR  High  44800.    IRR2  195903                                  WR-17           Highbank
**
**  Bryan Gage - Run-of-River Diversion Rights  *******!*******!*******!*******!*******!
**
WR Bryan  25400.    MUN2  198211       2    0.40                  WR-18           Bryan
WR Bryan  39000.    IND2  196105       2    0.65                  WR-19           Bryan
WR Bryan  34500.    IRR2  194510       2    0.05                  WR-20           Bryan
**
**  Hempstead Gage - Run-of-River Diversion Rights  ***!*******!*******!*******!*******!
**
WR  Hemp  49600.    IRR2  194510                                  WR-22           Hemp
WR  Hemp  95600.    IND2  196105                                  WR-21           Hemp
WR  Hemp  74500.    IRR2  200601                                  WR-23           Hemp
**
**  Hempstead Gage - Multiple-Reservoir System Diversion Right  *******!*******!*******!
**
WR  Hemp 900000.    MUN2  200601   2                              WR-24           SystemH
WS    PK 570240.
WSBelton 457600.
WSGeorge  37100.
WS Grang  65500.
```

Table 7.20 (Continued)
SIMD Input DAT File for Flood Control Example 7.2

```
**
**  Refilling Storage in Multiple-Reservoir System Reservoirs  !*******!*******!*******!
**
WR    PK                 888888                                WR-25           Refill
WS    PK 570240.
WRBelton                 888888                                WR-26           Refill
WSBelton 457600.
WRGeorge                 888888                                WR-27           Refill
WSGeorge  37100.
WR Grang                 888888                                WR-28           Refill
WS Grang  65500.
**
**-----!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!
**       1         2         3         4         5         6         7         8
**345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678
**-----!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!
**
**  Flood Flow Limits
**
FF WacoG       36200000.   NDAYS
FF Bryan       43440000.   NDAYS
FF  Hemp       43440000.   NDAYS
FF Camer        7240000.   NDAYS
**
**  Flood Control Reservoirs
**
FR    PK  910000  920000   0   2          665540 570240. 570240.
WS    PK
FR  Whit  910000  930000   0   2  49600. 2000000         627100.
WS  Whit
FR WacoL  910000  930000   0   2  39700.  726400         192100.
WS WacoL
FRBelton  910000  930000   0   2  19800. 1091320         457600.
WSBelton
FRGeorge  910000  930000   0   2   7930.  130800          37100.
WSGeorge
FR Grang  910000  930000   0   2  19800.  244200          65500.
WS Grang
**
FV    PK         570240.         588230.         606770.         625850.         645450.         665540.
FQ    PK              0.          20000.          44000.          69000.         100000.         150000.
**
**-----!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!-------!
** Reservoir Storage Volume (acre-feet) versus Surface Area (acres) Tables
**
SVBelton      0.     40.    160.    650.   1100.   1800.  20900.  58700. 123500. 218100. 304170. 457600. 470000. 535400. 606400. 683800. 768500. 861400. 1074200 1195600
SA            0.     17.     32.     63.    110.    200.   1760.   3270.   5290.   7580.   9261.  12258.  12500.  13660.  14800.  16170.  17700.  19470.  23260.  25380.
**
SVGeorge      0.      3.     97.    280.    640.   1250.   2610.   4170.   6310.  11500.  22900.  37100.  42570.  51990.  81600. 112500. 130800. 137370.
SA            0.      2.     19.     45.     77.    130.    237.    323.    410.    620.    958.   1310.   1483.   1657.   2291.   2859.   3241.   3329.
**
SV Grang      0.     76.    272.    960.   2200.   3460.   5310.   7030.  10310.  23950.  46600.  65500.  69960.  79500.  95670. 127500. 166300. 212600. 244200.
SA            0.     16.     52.    180.    344.    500.    750.    980.   1230.   1828.   3280.   4400.   4520.   5020.   5789.   7020.   8473.  10050.  11040.
**
SV    PK      0.    236.    865.   3579.  10447.  22038.  25810. 147410. 298092. 504100. 547414. 570240. 588230. 606700. 625850. 645450. 665540.
SA            0.     60.    216.    525.    962.   1403.   1500.   5675.   9875.  14440.  15803.  17700.  18270.  18820.  19340.  19850.  20340.
**
SV WacoL      0.      8.     36.   1438.   3509.   4804.  17091.  29704. 105675. 152500. 207106. 304510. 401742. 517448. 651274. 726360. 828325.
SA            0.      4.     12.    160.    338.    562.   2741.   3524.   5986.   7270.   8465.  11049.  13357.  15517.  18099.  19808.  21388.
**
SV  Whit      0.      9.   1145.   4843.  51240. 157245. 379108. 427400. 559219. 627100. 807330. 1120975 1500357 1950148 1999500 2100400
SA            0.     22.    237.    507.   3210.   7500.  15760.  16450.  21740.  23560.  28070.  34920.  41040.  48960.  49820.  51190.
**
** Reservoir Storage Volume (acre-feet) versus Elevation (feet) Table for Hydropower at Lake Whitney
**
PV  Whit   2630.  19600.  41710.  79990. 143200. 229400. 363600. 473100. 601800. 782000. 1095000 1473000 1970200 2071100
PE         448.8   470.0   480.0   490.0   500.0   510.0   520.0   527.0   533.0   540.0   550.0   560.0   571.0   573.0
ED
```

The beginning portion of the DCF file is reproduced as Table 7.21. The DCF file from Example 7.1 is adopted with the only change being extension of the *RT* records to include routing parameters for flow changes associated with flood control operations.

Table 7.21
Beginning of *SIMD* Input DCF File for Flood Control Example 7.2

```
**  WRAP-SIMD Input File Ch7Exam2Daily.DCF
**  Example 7.2 in Chapter 7 of the Daily Simulation Manual
**       1         2         3         4         5
**345678901234567890123456789012345678901234567890123456
**     !   !   !   !   !   !   !   !   !   !   !   !   !
**
RT    PK   1     2.8     2.0   1     1.3     1.0
RT  Whit   1     1.0     1.0   1     0.9     1.0
RT WacoG   1     0.7     1.0   1     0.7     1.0
RT  High   1     1.2     1.0   1     0.9     1.0
RTBelton   1     0.4     1.0   1     0.4     1.0
RTGeorge   1     0.6     1.0   1     0.6     1.0
RT Grang   1     0.6     1.0   1     0.4     1.0
RT Camer   1     0.9     1.0   1     0.8     1.0
RT Bryan   1     1.4     1.0   1     1.1     1.0
**
**     !   !   !   !   !   !   !   !   !   !   !   !   !
DC  Hemp      -4           1960       1    1969      12
DC    PK       3    Whit    1960       1    1969      12
DC WacoL       2
DC  High       4   WacoG    1960       1    1969      12
**
** Flows on DF records for the 3653 days from January 1960 through December 1969
** for control points Whit, Grang, Belton, WacoG, Camer, Bryan, and Hemp.
**       1         2         3         4         5         6         7         8
**34567890123456789012345678901234567890123456789012345678901234567890123456789 0
**       !         !         !         !         !         !         !         !
DF  Whit        1960         1         4
   2327.00   1710.00   1401.00   1992.00  10576.00   7301.00   7793.00   6770.00
   5261.00   4333.00   2836.00   2702.00   2655.00   3328.00   3898.00   6249.00
   6141.00   3333.00   2430.00   2108.00   2004.00   1691.00   1265.00   1018.00
   1405.00   1246.00   1599.00   1762.00    562.00   1427.00   1197.00
DF  Whit        1960         2         4
   1208.00   1079.00   3524.00   2567.00   1839.00   3544.00   3075.00   2389.00
   2567.00   1315.00   1192.00    721.00    927.00    816.00   1054.00   1418.00
   1206.00    376.00    261.00   1563.00   1133.00    551.00   2091.00    560.00
    491.00    407.00    982.00   1038.00   1070.00
DF  Whit        1960         3         4
    644.00    823.00    552.00    708.00   1019.00    811.00   1069.00    822.00
    246.00    690.00    207.00    289.00    359.00    451.00    455.00    508.00
    372.00    689.00    638.00    423.00    616.00    966.00    448.00    501.00
    320.00    654.00    533.00    455.00   1163.00    683.00    561.00
DF  Whit        1960         4         4
    459.00    412.00    404.00    410.00    424.00    444.00    444.00    432.00
    428.00    429.00    413.00    379.00    414.00    126.00     82.00    495.00
   1020.00    860.00    564.00    928.00    298.00    198.00    137.00   1395.00
   2487.00   1341.00   9437.00   3778.00   4223.00   2644.00
```

The *TABLES* input TIN file is reproduced as Table 7.22. Essentially all of the types of tables developed without flood control operations are still pertinent with flood control operations. However, application of *TABLES* in this example is limited to *7FFA* record flood frequency analyses and creating a DSS file with *6NAT*, *6REG*, and *6STO* records for use with HEC-DSSVue to develop plots of daily naturalized and regulated flows and storage contents.

Table 7.22
TABLES Input TIN File for Flood Control Example 7.2

```
**       1         2         3         4         5
**  5678901234567890123456789012345678901234567890l2
**      !   !   !   !   !   !   !   !   !   !   !   !
6NAT        4   0   0   0
6REG        4   0   0   0
6STO        4   0   0   6
IDEN       PK    Whit   WacoL  Belton  George   Grang
7FFA   1    2   0   0   5    -0.2
7FFA   2    2   0   0   5    -0.2
7FFA   4    2   0   0   5    -0.2
7FFA   3    2   1   6   5    -0.2
IDEN       PK    Whit   WacoL  Belton  George   Grang
ENDF
```

<u>*Simulation Results*</u>

SIMD creates SUB, AFF, and message MSS and SMM files. The first year of the 58-year *SIMD* annual flood frequency AFF file is shown as Table 7.23. *TABLES* reads the SUB, AFF, and TIN files and creates message TMS, output TOU, and data storage system DSS files. The *TABLES* output TOU file is reproduced as Table 7.24. The plots in Figures 7.2−7.19 were created with HEC-DSSVue from a DSS file created with *TABLES* in accordance with the *6NAT*, *6REG*, and *6STO* records in the TIN file of Table 7.22. End-of-day (midnight) storage contents for the six reservoirs in acre-feet and daily naturalized and regulated stream flows in acre-feet/day are plotted for the 21,185 days of the 1940-1997 hydrologic period-of-analysis.

The regulated flows at control points Camer and Hemp in Figures 7.15 and 7.19 can be compared with the *FF* record field 3 allowable flood flow limits listed in Table 7.19 and noted below the figure captions. The flood control limits are greatly exceeded many times during the 1940-1997 simulation. Operations of the five reservoirs are based on making no releases from the flood control pools that contribute to regulated river flows exceeding the non-damaging flood flow limits at these downstream control points. However, flows entering the river below the dams cause flooding at these sites even though the gates at the dams are closed. The flood control dams reduce but do not control the flood flows at these downstream sites.

The pool storage capacities and maximum release rates at the dams from Table 7.18 are noted above the storage plots for the six reservoirs. The regulated flows at control points Whit, WacoL, Belton, George, and Grang represent reservoir releases. As shown in Figures 7.2 through 7.13, the regulated flows at the dam sites exceed the maximum release rates only during extreme flood events when the flood control storage capacity is exceeded.

Possum Kingdom Reservoir at Control Point PK

storage capacity at top of surcharge storage = 665,540 acre-feet
conservation storage capacity = 570,240 acre-feet

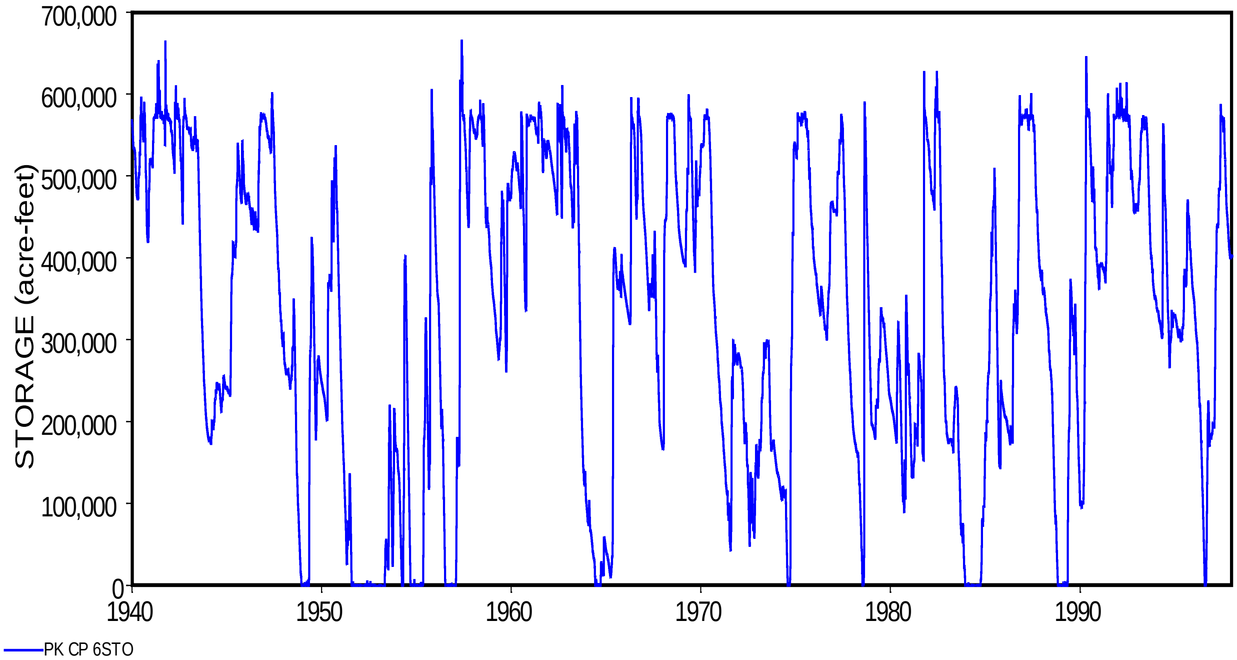

Figure 7.2 Daily Storage Volume of Possum Kingdom Reservoir at Control Point PK

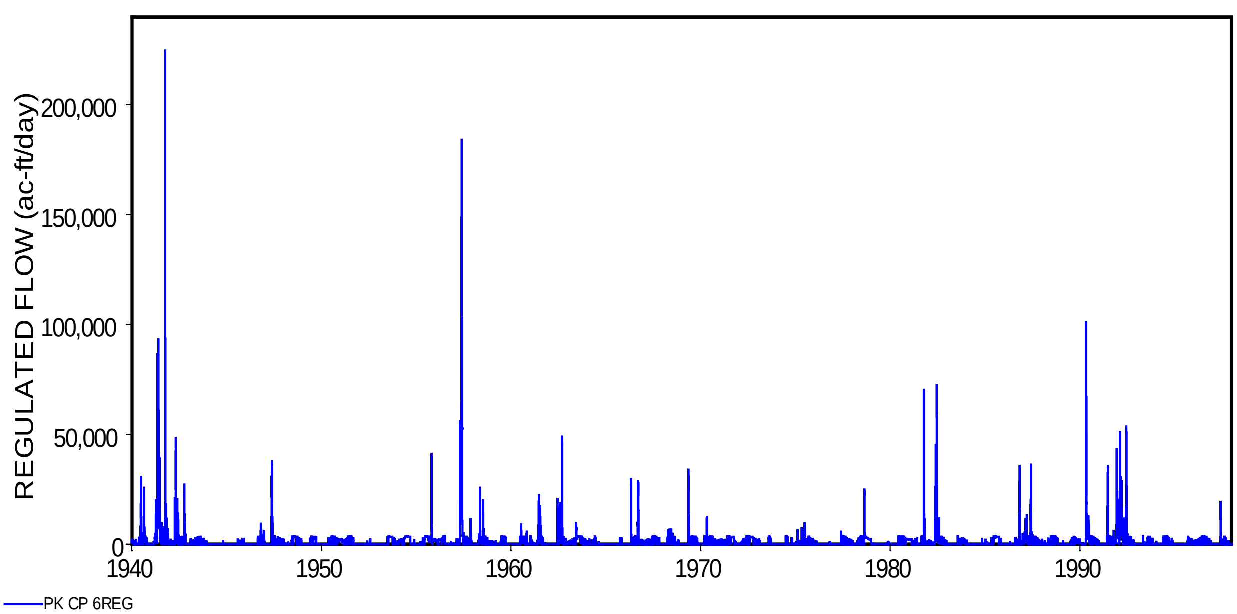

Figure 7.3 Daily Regulated Flow at Control Point PK

Whitney Reservoir at Control Point Whit

storage capacity at top of flood control pool = 2,000,000 acre-feet
conservation storage capacity = 627,100 acre-feet
maximum allowable release at dam = 49,600 acre-feet/day

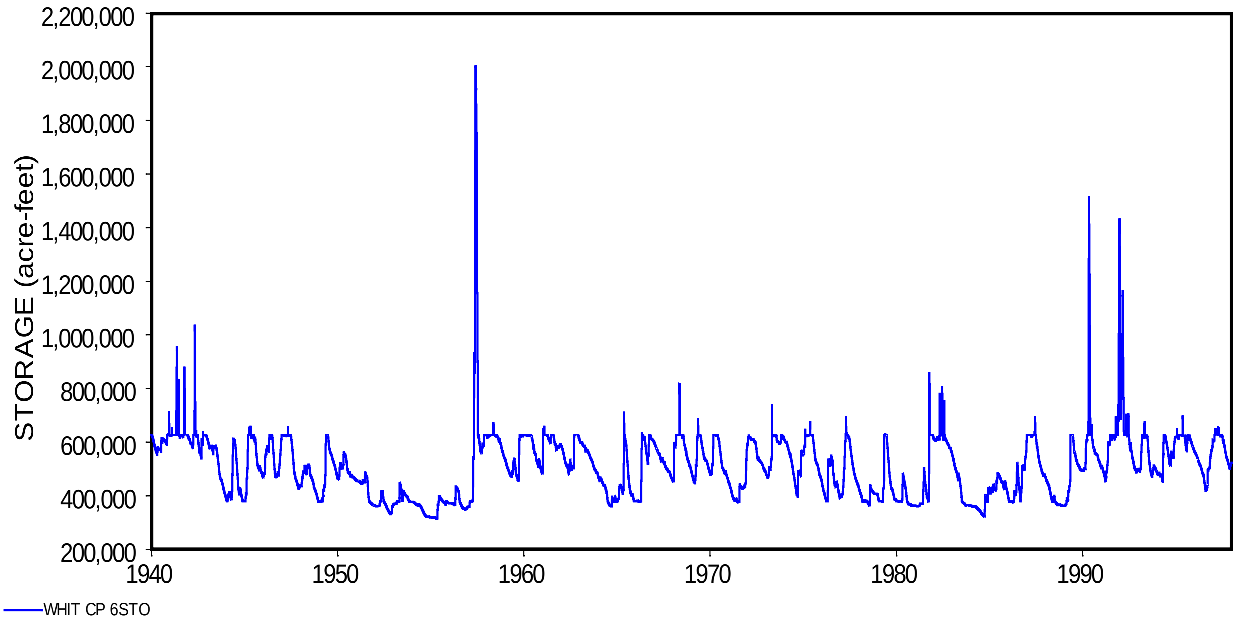

Figure 7.4 Daily Storage Volume of Whitney Reservoir at Control Point Whit

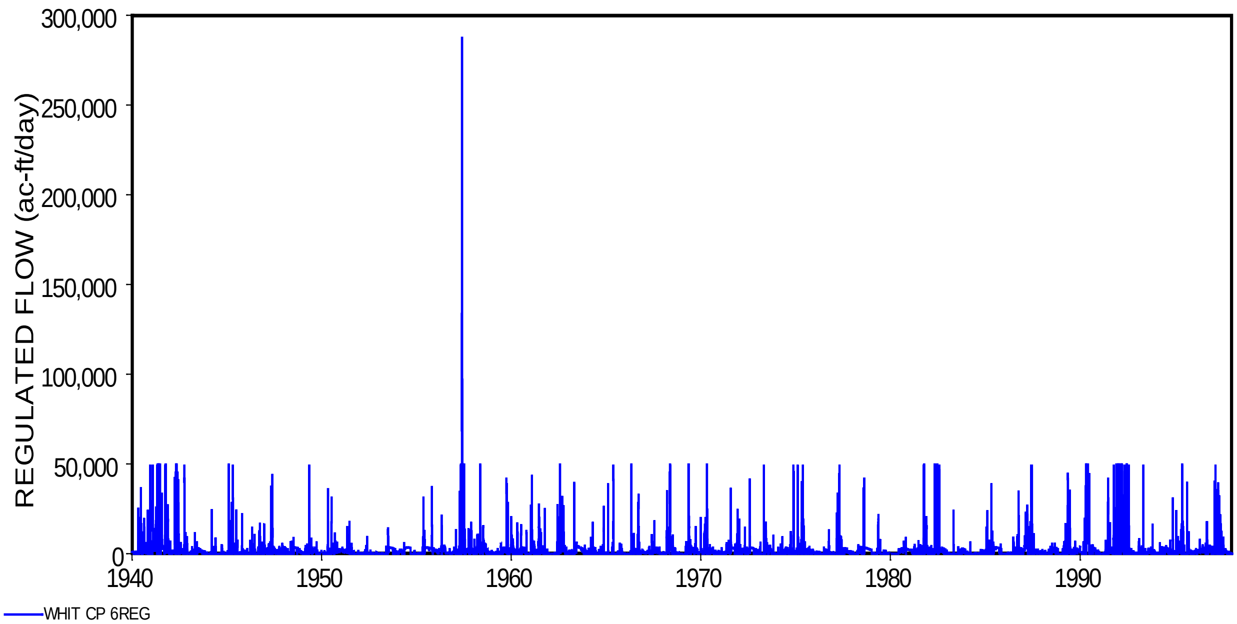

Figure 7.5 Daily Regulated Flow at Control Point Whit

Waco Reservoir at Control Point WacoL

storage capacity at top of flood control pool = 726,400 acre-feet
conservation storage capacity = 192,100 acre-feet
maximum allowable release at dam = 39,700 acre-feet/day

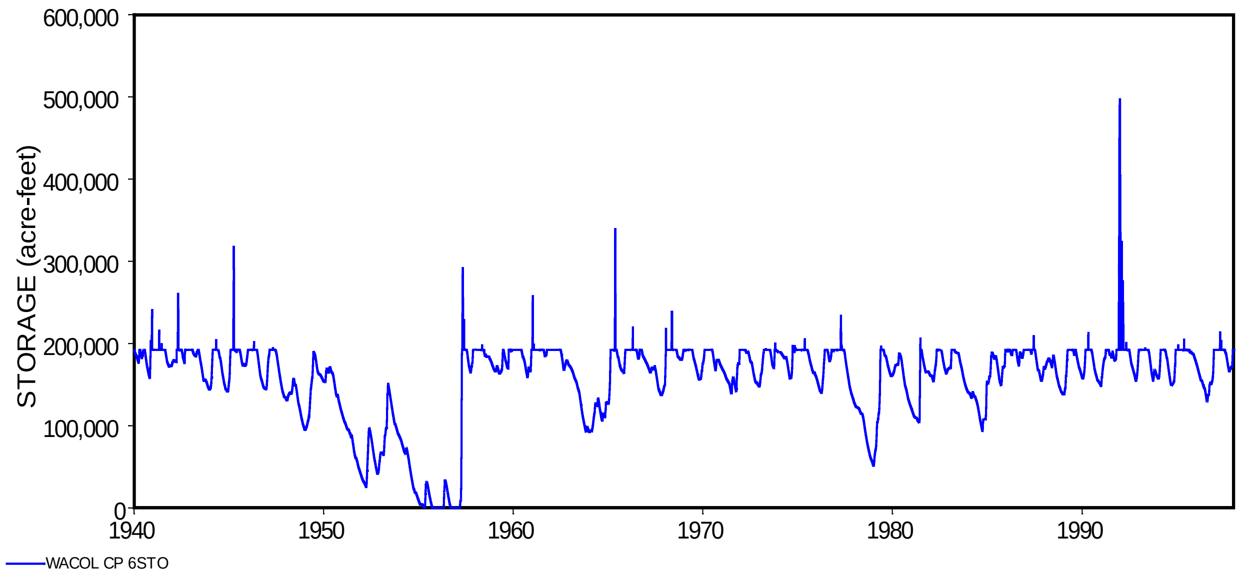

Figure 7.6 Daily Storage Volume of Waco Reservoir at Control Point WacoL

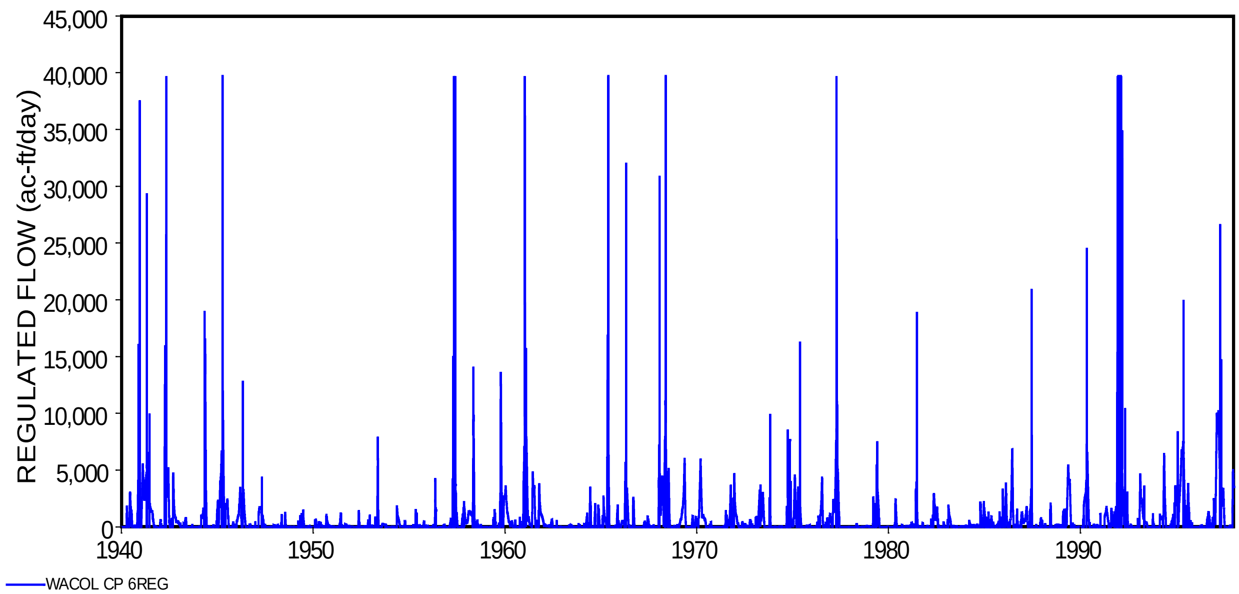

Figure 7.7 Daily Regulated Flow at Control Point WacoL

Belton Reservoir at Control Point Belton

storage capacity at top of flood control pool = 1,091,320 acre-feet
conservation storage capacity = 457,600 acre-feet
maximum allowable release at dam = 19,800 acre-feet/day

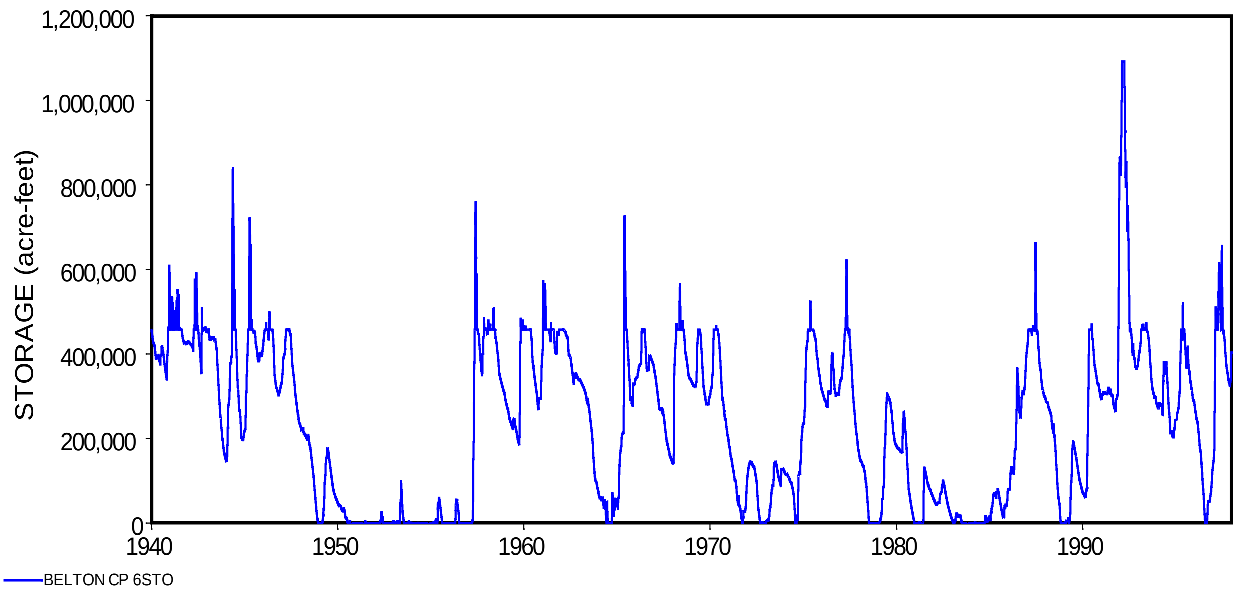

Figure 7.8 Daily Storage Volume of Belton Reservoir at Control Point Belton

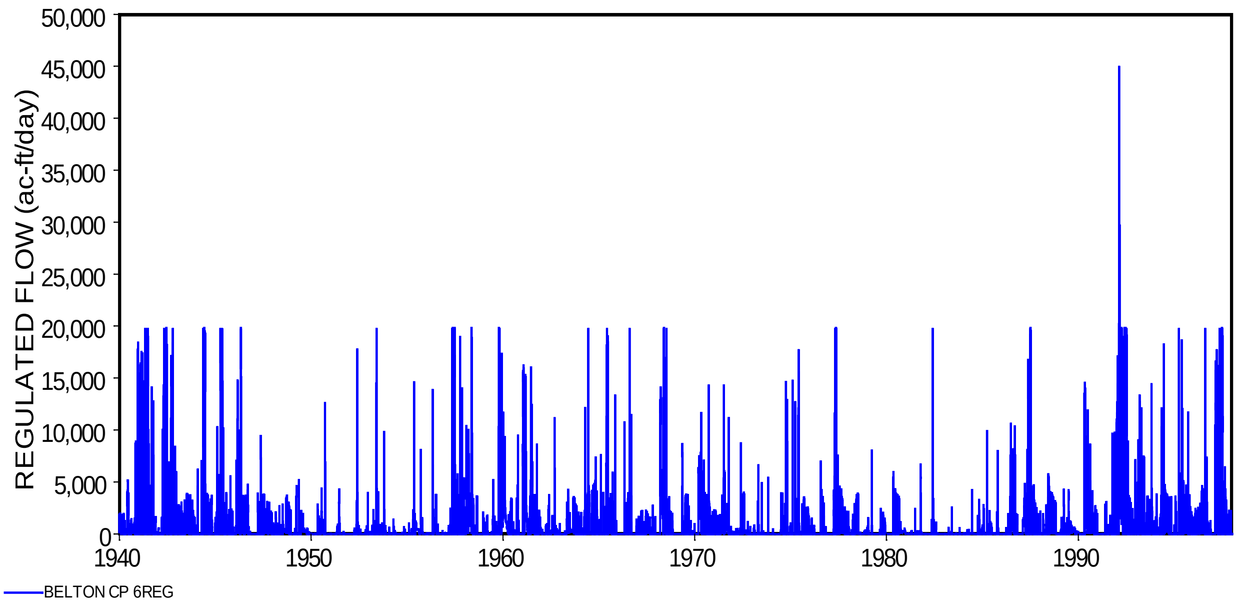

Figure 7.9 Daily Regulated Flow at Control Point Belton

Georgetown Reservoir at Control Point George

storage capacity at top of flood control pool = 130,800 acre-feet
conservation storage capacity = 37,100 acre-feet
maximum allowable release at dam = 7,930 acre-feet/day

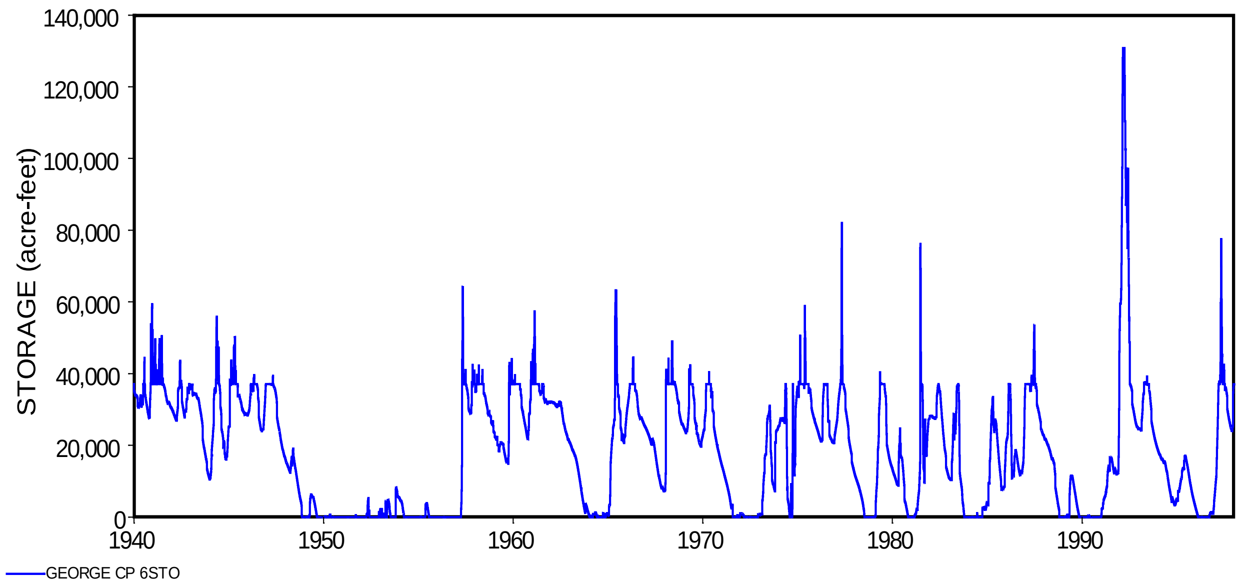

Figure 7.10 Daily Storage Volume of Georgetown Reservoir at Control Point George

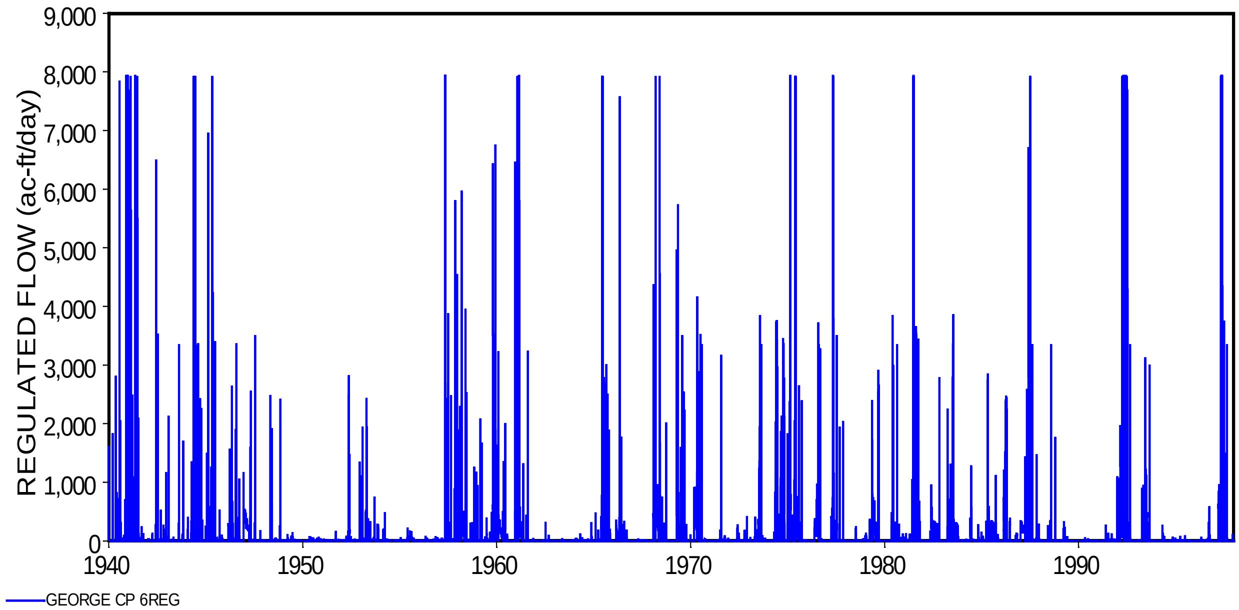

Figure 7.11 Daily Regulated Flow at Control Point George

Granger Reservoir at Control Point Grang

storage capacity at top of flood control pool = 244,200 acre-feet
conservation storage capacity = 65,500 acre-feet
maximum allowable release at dam = 19,800 acre-feet/day

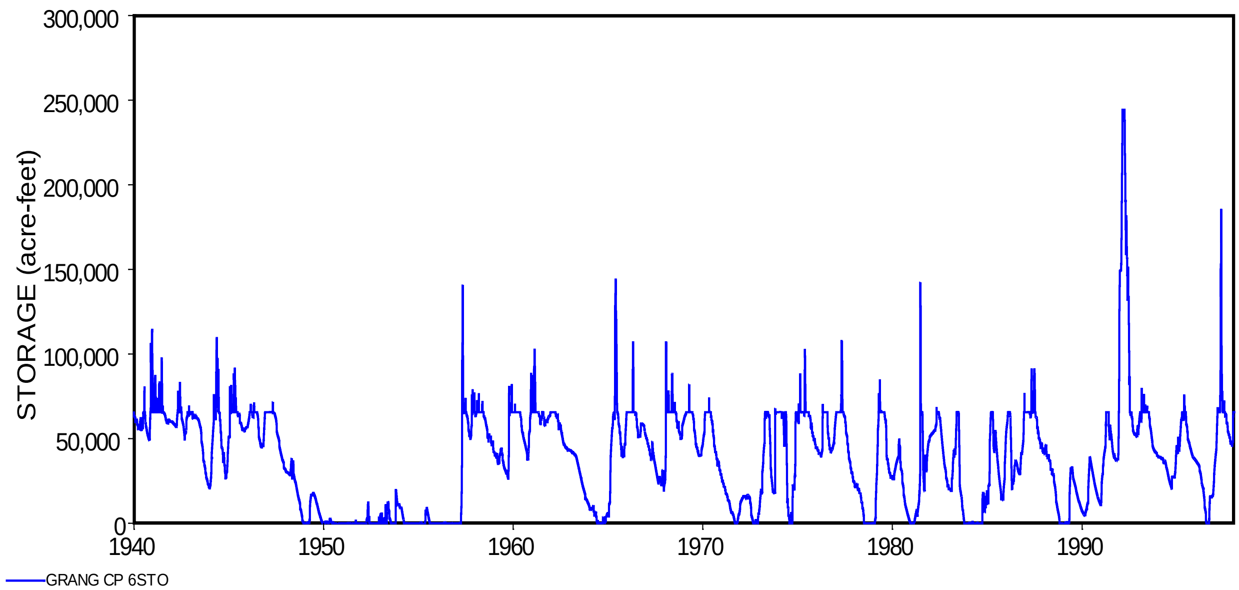

Figure 7.12 Daily Storage Volume of Granger Reservoir at Control Point Grang

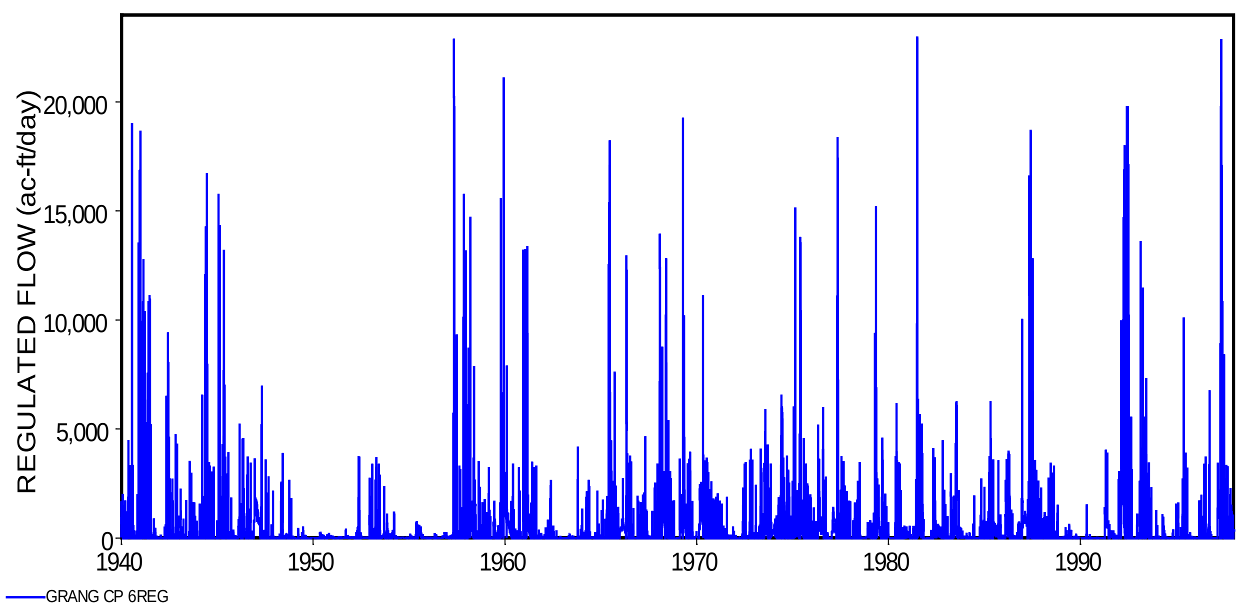

Figure 7.13 Daily Regulated Flow at Control Point Grang

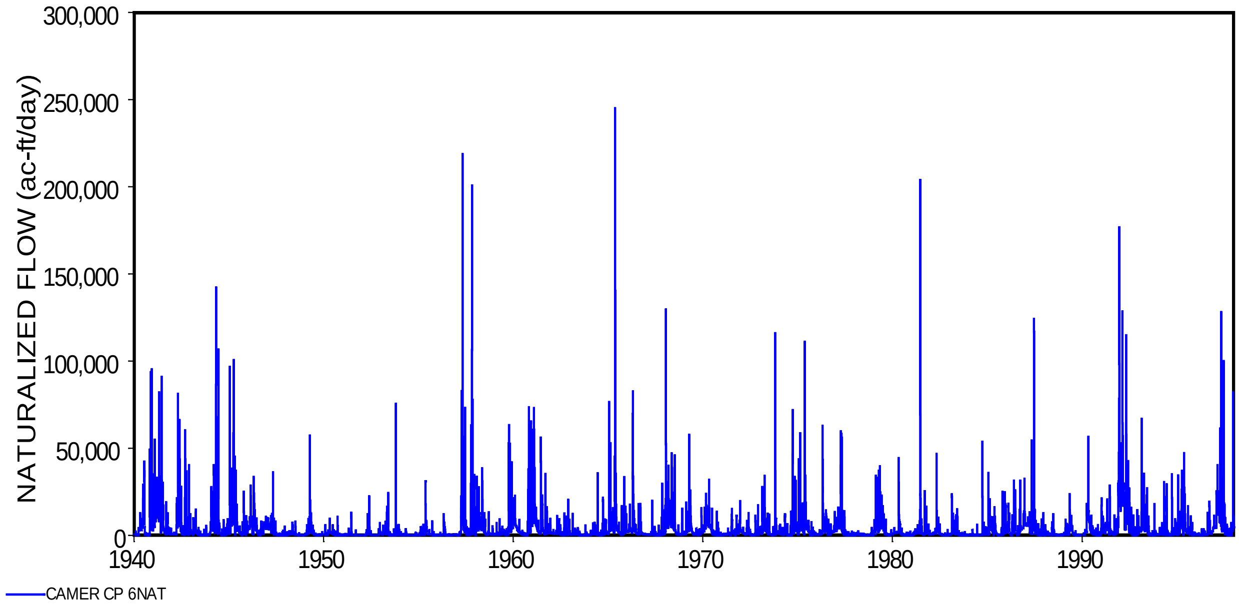

Figure 7.14 Daily Naturalized Flow at Control Point Camer

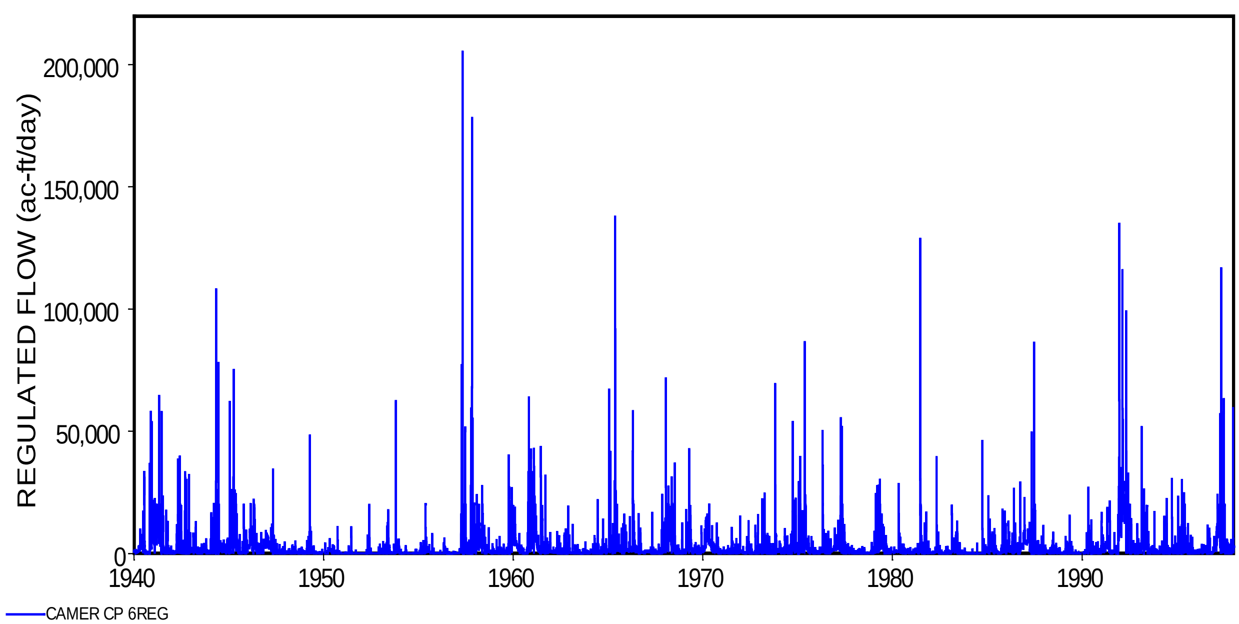

Figure 7.15 Daily Regulated Flow at Control Point Camer

maximum allowable flood flow at Camer = 39,670 acre-feet/day

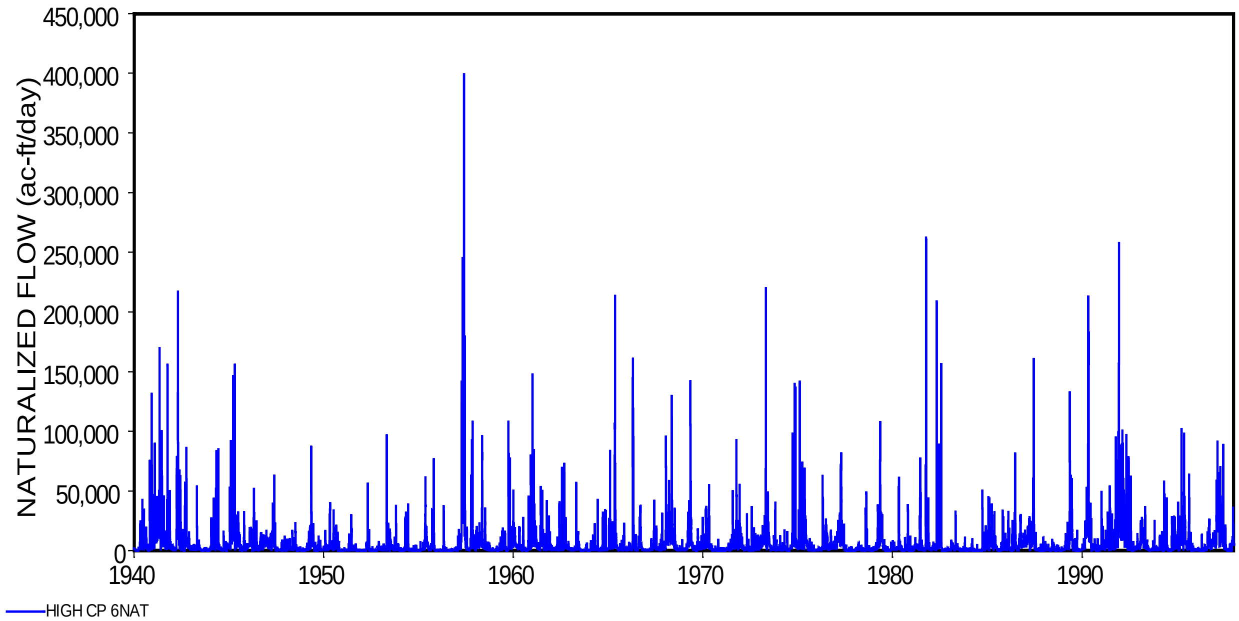

Figure 7.16 Daily Naturalized Flow at Control Point High

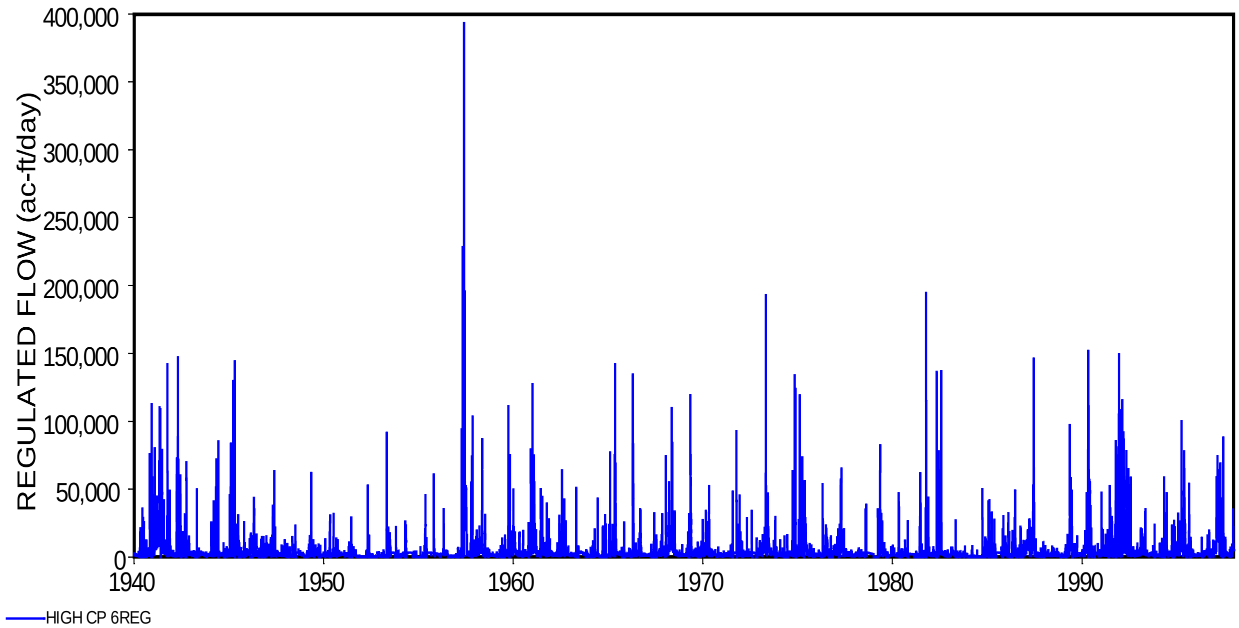

Figure 7.17 Daily Regulated Flow at Control Point High

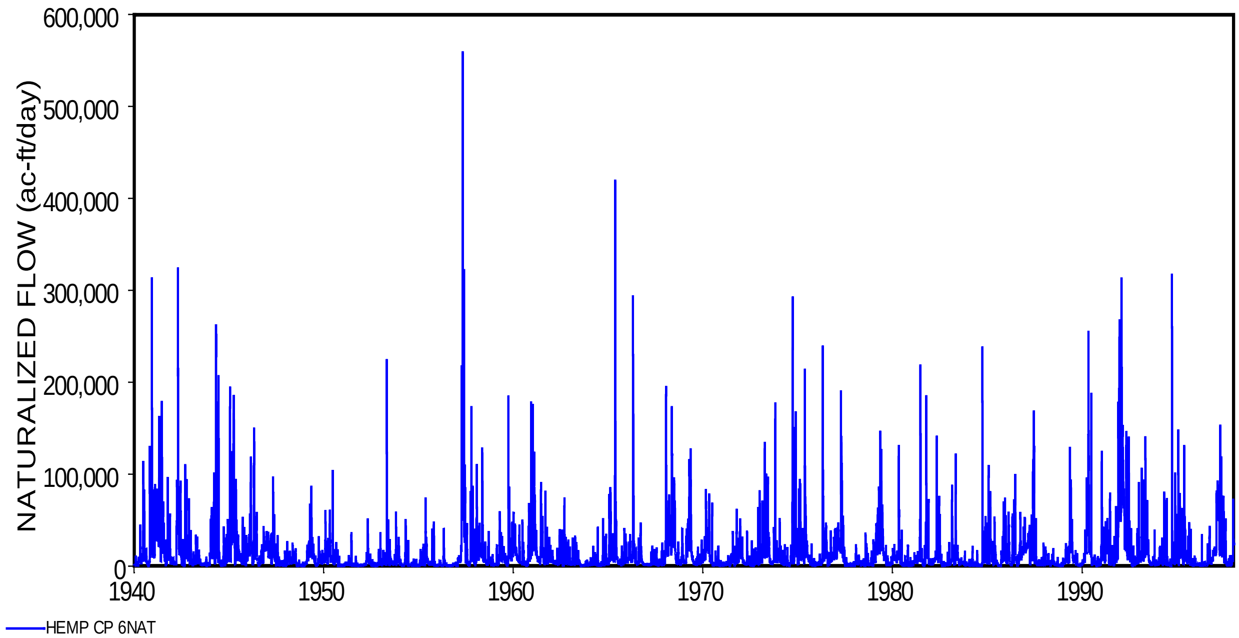

Figure 7.18 Daily Naturalized Flow at Control Point Hemp

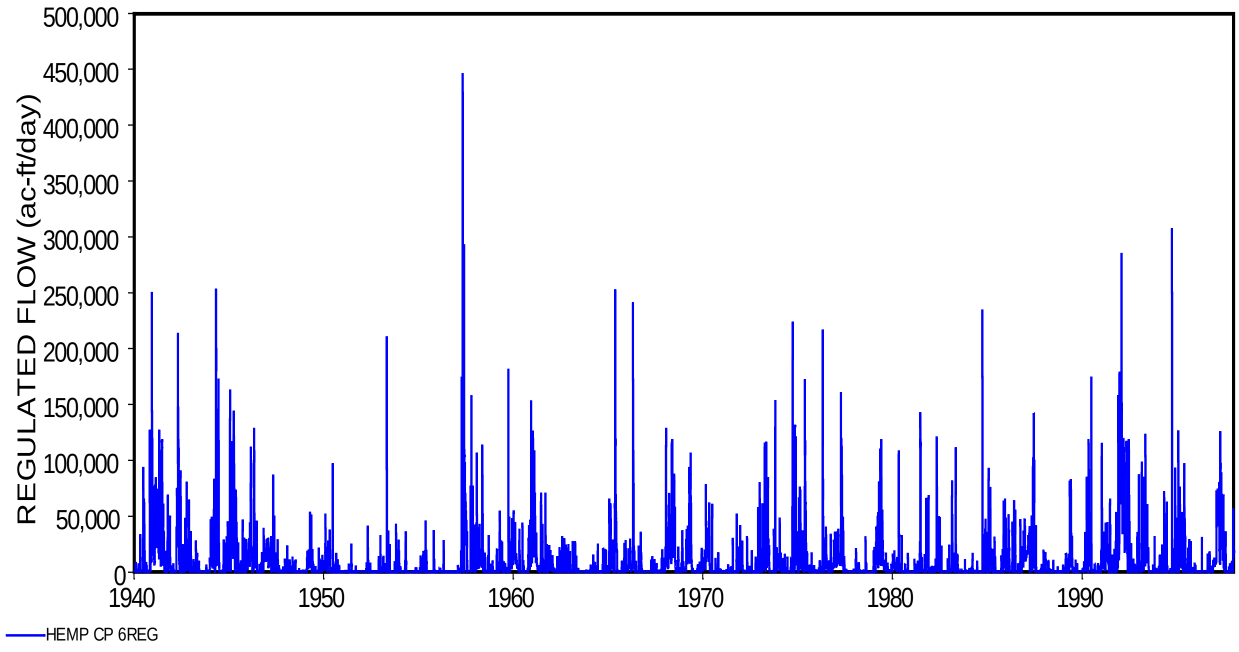

Figure 7.19 Daily Regulated Flow at Control Point Hemp

maximum allowable flood flow at Hemp = 119,010 acre-feet/day

End-of-day (midnight) storage contents for the 1940-1997 simulation for the six reservoirs are plotted in Figures 7.2, 7.4, 7.6, 7.8, 7.10, and 7.12. The regulated flows just below the dams plotted in Figures 7.3, 7.5, 7.7, 7.9, 7.11, and 7.13 represent flows through the dam outlet structures which include the types of releases noted in the following paragraph.

In the model, any time the total storage capacity of the conservation and flood control pools is full, inflows are assumed to instantaneous flow though a reservoir (outflow=inflow). *SIMD* allows surcharge storage above the crest of uncontrolled (ungated) spillways located at or above the top of conservation and/or controlled flood control pools (Figure 5.1) to be modeled with a storage-outflow relationship defined by *FV* and *FQ* records. However, the *FV/FQ* record rating curve feature is applied only for Possum Kingdom Reservoir in this example. Possum Kingdom is a conservation-only reservoir with no designated flood control storage capacity. The other five reservoirs contain large controlled flood control pools. Filling storage and releases from the flood control pool are governed by flood control operating rules based on the maximum allowable flow rates listed in Tables 7.18 and 7.19. The regulated flows at the dam sites also include hydropower releases at Whitney Reservoir and releases from conservation pools for the multiple-reservoir water supply diversion rights at control points Camer and Hemp.

The Possum Kingdom surcharge pool capacity is exceeded frequently during the 58-year simulation. The flood control pool of Lake Waco is not exceeded during of the simulation. The flood control storage capacity of each of the other four reservoirs is exceed once during the simulation. The flood control pools retain flood waters during a number of significant floods. Major floods occur at different times and with varying severity in different regions of this large river basin. The April-May 1957 flood dramatically filled storage at all five reservoirs and ended a severe multiple-year drought. The flood control pools were empty at the beginning of the April-May 1957 flood. Likewise, conservation storage was empty or significantly drawn down in all of the reservoirs. The 1957 flood exceeded the flood control storage capacity of Whitney reservoir. A 1992 flood was the only flood to exceed the flood control capacity of Belton, Georgetown, and Granger Reservoirs.

Annual Flood Frequency Analyses

The beginning of the annual flood frequency AFF file is reproduced as Table 7.23 to illustrate its format. The maximum daily naturalized and regulated flow volumes, end-of-day storage volume, and excess flow (defined later) at the eleven control points are tabulated in the AFF file for each of the 58 years of the simulation. The AFF file was created with *SIMD* for use in developing the *TABLES 7FFA* record flood frequency tables reproduced as Table 7.23. The *TABLES* output TOU file of Table 7.24 presents the results of applying the log-Pearson type III probability distribution to regulated and naturalized flows at the eleven control points, storage volumes in the six reservoirs, and the summation of storage and excess flow for the reservoirs.

The *7FFA* frequency tables show the values of the random variable which have the probability of being equaled or exceeded in any year as expressed by the exceedance frequency and recurrence intervals in the table heading. Auxiliary tables provide statistics for the data from the AFF file and the logarithms of these data used in the frequency analyses. *TABLES* also has capabilities, not applied in this example, to develop expected annual economic flood damage tables along with the frequency analysis tables, as described in Chapter 5.

Table 7.23
Beginning of *SIMD* Output AFF File for Flood Control Example 7.2

```
WRAP-SIMD (July 2012) Flood Frequency Analysis File
    58    11
YEAR    CPID    NAT-FLOW    REG-FLOW     STORAGE EXCESS FLOW
1940      PK     46962.6     31062.9    596776.6     340029.
1940    Whit     35719.3     49600.0    712170.4          0.
1940   WacoL      5068.7     37569.9    241868.5          0.
1940   WacoG     92579.3     75581.7        -1.0          0.
1940    High    132267.0    113496.8        -1.0          0.
1940  Belton     42434.7     18499.7    608337.8          0.
1940  George      7858.9      7930.0     59620.4          0.
1940   Grang     25287.2     18971.0    114922.2          0.
1940   Camer     95221.4     58379.2        -1.0          0.
1940   Bryan    220453.6    200017.8        -1.0          0.
1940    Hemp    313784.2    250742.6        -1.0          0.
1941      PK    307701.5    225053.7    665540.0    3059240.
1941    Whit    239156.8     49600.0    957343.4          0.
1941   WacoL      6729.3     29395.0    216465.5          0.
1941   WacoG    156433.6    112655.3        -1.0          0.
```

Table 7.24
TABLES Output TOU File for Flood Control Example 7.2

FLOOD FREQUENCIES FOR NATURALIZED STREAMFLOWS

CONTROL POINT	1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	EXPECTED VALUE
	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)									
PK	4372.	30393.	66897.	103000.	165622.	226947.	302954.	396457.	552517.	50539.
Whit	8262.	54723.	109930.	158767.	235502.	304198.	383280.	473884.	613405.	79269.
WacoL	457.	4650.	9504.	13468.	19176.	23855.	28844.	34138.	41593.	6552.
WacoG	13087.	69756.	126120.	171417.	237301.	292461.	352694.	418380.	514196.	89760.
High	14201.	85039.	151129.	201124.	269811.	324278.	381105.	440381.	522570.	105562.
Belton	1055.	20167.	44212.	63109.	88717.	108315.	127924.	147406.	172778.	29448.
George	80.	2549.	6782.	10719.	16798.	21997.	27662.	33750.	42376.	4733.
Grang	423.	9290.	22118.	33147.	49258.	62445.	76366.	90916.	110956.	15083.
Camer	4067.	46992.	98096.	139886.	199820.	248656.	300388.	354883.	430935.	67292.
Bryan	19288.	117259.	217129.	297363.	413500.	510089.	614851.	728265.	892199.	153193.
Hemp	15760.	129865.	239885.	320976.	428529.	510587.	593270.	676486.	787100.	163602.

STATISTICS FOR PEAK ANNUAL NATURALIZED STREAMFLOW

					Statistics for Logarithms of Annual Peaks				
CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
PK	49750.	64973.	4846.	355639.	4.4972	0.3958	-0.2000	0.3782	0.2195
Whit	77779.	78022.	5843.	381986.	4.7404	0.3582	-0.2000	0.1135	0.0376
WacoL	6311.	5447.	368.	27762.	3.6475	0.3874	-0.2000	-0.3493	-0.3089
WacoG	88641.	67899.	10015.	374234.	4.8415	0.3075	-0.2000	0.0059	-0.0414
High	104452.	74105.	10043.	398926.	4.9180	0.3073	-0.2000	-0.2370	-0.2275
Belton	28271.	29145.	506.	166330.	4.2603	0.4495	-0.2000	-0.7901	-0.5954
George	4282.	4867.	60.	28956.	3.3629	0.5473	-0.2000	-0.5985	-0.4776
Grang	13983.	14293.	516.	81544.	3.9285	0.4862	-0.2000	-0.6168	-0.4893
Camer	64243.	54694.	4137.	245584.	4.6483	0.4021	-0.2000	-0.4157	-0.3555
Bryan	150956.	127619.	26389.	859923.	5.0632	0.3232	-0.2000	-0.0822	-0.1103
Hemp	159199.	108036.	20126.	558561.	5.0898	0.3393	-0.2000	-0.5109	-0.4202

Table 7.24 Continued
TABLES Output TOU File for Flood Control Example 7.2

FLOOD FREQUENCIES FOR REGULATED STREAMFLOWS

CONTROL POINT	1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	EXPECTED VALUE
	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)									
PK	717.	8488.	26569.	51023.	106888.	176599.	282051.	439005.	764078.	26398.
Whit	5166.	33789.	58192.	75269.	97121.	113320.	129308.	145107.	165718.	40013.
WacoL	198.	6728.	20432.	35315.	61752.	87430.	118489.	155375.	213838.	15659.
WacoG	11680.	54895.	92717.	121046.	159977.	190988.	223544.	257763.	305695.	65872.
High	12415.	73588.	127298.	166296.	218025.	257749.	298134.	339232.	394669.	88496.
Belton	1631.	12010.	20209.	25523.	31851.	36227.	40305.	44114.	48777.	13702.
George	17.	2055.	7110.	12365.	20853.	28218.	36219.	44709.	56466.	5133.
Grang	204.	6376.	15356.	22678.	32721.	40421.	48095.	55667.	65423.	10182.
Camer	3310.	34433.	71042.	101200.	144924.	180986.	219612.	260772.	319002.	49052.
Bryan	15884.	90727.	166273.	227059.	315356.	389110.	469439.	556786.	683725.	117819.
Hemp	11598.	102706.	194430.	263417.	356276.	427995.	500922.	574925.	674144.	132515.

STATISTICS FOR PEAK ANNUAL REGULATED STREAMFLOW

					Statistics for Logarithms of Annual Peaks				
CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
PK	23479.	40828.	1944.	225054.	3.9702	0.5590	-0.2000	0.7586	0.4465
Whit	40330.	36453.	5706.	287270.	4.5072	0.3012	-0.2000	-0.5260	-0.4303
WacoL	13318.	14253.	243.	39700.	3.8014	0.5976	-0.2000	-0.2900	-0.2663
WacoG	66169.	50757.	8126.	363426.	4.7338	0.2756	-0.2000	-0.1018	-0.1254
High	88086.	61658.	8762.	393203.	4.8515	0.2970	-0.2000	-0.3498	-0.3093
Belton	13554.	7595.	1458.	45038.	4.0479	0.3007	-0.2000	-0.8596	-0.6354
George	3748.	3052.	45.	7930.	3.2344	0.7206	-0.2000	-0.9044	-0.6571
Grang	9020.	7094.	268.	22947.	3.7472	0.5125	-0.2000	-0.9461	-0.6760
Camer	47069.	40599.	3400.	205684.	4.5173	0.3920	-0.2000	-0.3387	-0.3013
Bryan	116764.	104543.	17985.	751660.	4.9538	0.3161	-0.2000	-0.0375	-0.0754
Hemp	127947.	87734.	16862.	446550.	4.9876	0.3521	-0.2000	-0.4946	-0.4093

FLOOD FREQUENCIES FOR SUMMATION OF RESERVOIR STORAGE AND EXCESS FLOW

CONTROL POINT	1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	EXPECTED VALUE
	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%)									
PK	34024.	650023.	1258636.	1651486.	2098512.	2388920.	2643284.	2865694.	3117026.	811082.
Whit	346828.	626128.	854463.	1028526.	1276166.	1481938.	1706991.	1954131.	2319505.	689215.
WacoL	50648.	199436.	271985.	309242.	346532.	368680.	387040.	402430.	419193.	195947.
Belton	4264.	293449.	757243.	1118148.	1576798.	1899104.	2195872.	2465808.	2782013.	485506.
George	261.	24375.	69770.	108483.	161236.	200566.	238437.	274316.	318200.	45783.
Grang	1654.	57847.	130021.	182027.	245569.	289189.	328886.	364753.	406633.	83339.

STATISTICS FOR SUMMATION OF PEAK ANNUAL RESERVOIR STORAGE AND EXCESS FLOW

					Statistics for Logarithms of Annual Peaks				
CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
PK	774935.	675478.	4615.	3724780.	5.7505	0.4096	-0.2000	-2.1614	-0.9285
Whit	700479.	368442.	376993.	2888235.	5.8133	0.1494	-0.2000	1.9152	0.6712
WacoL	201906.	76989.	31890.	496932.	5.2712	0.1913	-0.2000	-1.9301	-0.9083
Belton	384999.	285038.	601.	1607188.	5.3779	0.5875	-0.2000	-2.1573	-0.9282
George	35117.	28538.	118.	172210.	4.2959	0.6409	-0.2000	-1.6513	-0.8627
Grang	72933.	59982.	568.	398071.	4.6890	0.4978	-0.2000	-1.8366	-0.8957

Table 7.24 Continued
TABLES Output TOU File for Flood Control Example 7.2

FLOOD FREQUENCIES FOR RESERVOIR STORAGE

CONTROL POINT	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%) 1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	EXPECTED VALUE
PK	59728.	458915.	788514.	1007524.	1273577.	1460848.	1637704.	1805009.	2012642.	533911.
Whit	356637.	625641.	833457.	987277.	1200904.	1374625.	1561355.	1763051.	2055766.	676574.
WacoL	50648.	199436.	271985.	309242.	346532.	368680.	387040.	402430.	419193.	195947.
Belton	4336.	291274.	746621.	1099084.	1545335.	1857977.	2145210.	2405955.	2710768.	478272.
George	263.	24273.	69031.	106951.	158341.	196473.	233054.	267593.	309681.	45199.
Grang	1691.	57393.	127354.	177075.	237161.	278006.	314895.	347988.	386331.	81492.

STATISTICS FOR PEAK ANNUAL RESERVOIR STORAGE

CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	Statistics for Logarithms of Annual Peaks MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
PK	482306.	154335.	4615.	665540.	5.6309	0.3102	-0.2000	-4.8061	-0.5999
Whit	685164.	284901.	376993.	2000000.	5.8105	0.1384	-0.2000	1.4096	0.6187
WacoL	201906.	76989.	31890.	496932.	5.2712	0.1913	-0.2000	-1.9301	-0.9083
Belton	376105.	252413.	601.	1091320.	5.3750	0.5838	-0.2000	-2.2094	-0.9308
George	34403.	25392.	118.	130800.	4.2939	0.6380	-0.2000	-1.6833	-0.8692
Grang	70280.	47441.	568.	244200.	4.6853	0.4917	-0.2000	-1.9457	-0.9102

PEAK ANNUAL RESERVOIR STORAGE

RANK	P(%)	PK	Whit	WacoL	Belton	George	Grang
1	1.69	665540.0	2000000.0	496931.5	1091320.0	130800.0	244200.0
2	3.39	665540.0	1513586.9	496834.0	865370.7	82052.3	185660.0
3	5.08	646128.3	1430604.0	340190.4	841072.1	77816.6	148931.7
4	6.78	628332.6	1404023.4	318715.8	760540.7	76440.4	143839.9
5	8.47	626673.1	1038785.6	292621.4	728766.2	64407.6	142147.3
6	10.17	614414.2	957343.4	260157.6	720520.8	63196.3	140751.3
7	11.86	610980.1	861899.7	258719.1	663661.0	59620.4	114922.2
8	13.56	610392.6	821370.7	241868.5	658154.7	59152.8	109279.8
9	15.25	606114.4	809110.4	238279.3	621465.0	57387.6	108120.4
10	16.95	604519.5	742216.6	234653.9	608337.8	55966.1	106861.0
11	18.64	602242.5	713846.3	220707.0	591217.0	55833.0	106732.4
12	20.34	601105.2	712170.4	216465.5	574230.8	53644.7	103011.9
13	22.03	599393.6	699467.4	214600.9	566481.3	50440.0	102447.5
14	23.73	598493.6	698746.1	213966.4	553328.4	50432.4	97861.8
15	25.42	596776.6	696420.3	209849.6	525993.8	48981.1	91832.4
16	27.12	596062.2	689795.7	207135.4	522904.4	44508.1	91395.1
17	28.81	593066.6	679042.5	206256.4	510772.4	44377.5	88911.1
18	30.51	590386.9	677765.7	205904.9	500321.5	43605.4	84971.5
19	32.20	589315.0	670147.5	205213.5	485773.3	43196.9	82796.1
20	33.90	588004.8	661882.9	202725.4	472061.1	42521.4	82168.6
21	35.59	581755.0	661726.9	200992.6	469357.9	42308.2	81926.7
22	37.29	579416.9	659833.1	198824.8	468441.7	40644.5	80006.8
23	38.98	579248.8	658867.7	198207.7	466613.2	40331.8	76877.5
24	40.68	577575.9	633032.7	196153.2	461300.4	39677.5	76736.1
25	42.37	577256.4	630590.6	195452.0	458271.1	39619.3	75424.5
26	44.07	576748.7	627540.4	195188.8	457600.0	39161.1	74327.1
27	45.76	575893.2	627100.0	192308.1	457600.0	37100.0	71637.2
28	47.46	574086.4	627100.0	192100.0	457600.0	37100.0	71417.5

Table 7.24 Continued
TABLES Output TOU File for Flood Control Example 7.2

PEAK ANNUAL RESERVOIR STORAGE - Continued

RANK	P(%)	PK	Whit	WacoL	Belton	George	Grang
29	49.15	571319.0	627100.0	192100.0	402772.2	37100.0	70361.6
30	50.85	563790.9	627100.0	192100.0	401897.9	37100.0	68482.8
31	52.54	543749.7	627100.0	192100.0	380923.1	37100.0	67633.3
32	54.24	540653.8	627100.0	192100.0	362526.5	36889.6	65500.0
33	55.93	537202.8	627100.0	192100.0	339251.5	33437.4	65500.0
34	57.63	508270.2	623955.6	192100.0	306704.9	32343.4	65500.0
35	59.32	490798.9	613976.2	192100.0	296563.3	31072.2	65500.0
36	61.02	470992.5	612114.7	192100.0	286484.6	24805.0	65500.0
37	62.71	468648.6	611034.0	192100.0	265459.2	24678.4	51497.2
38	64.41	451781.9	607853.8	192100.0	235020.5	22433.5	50107.5
39	66.10	433134.0	607121.2	192100.0	230580.2	20626.3	46433.9
40	67.80	425485.1	601631.6	192100.0	194678.5	19410.9	46129.0
41	69.49	412941.9	598762.3	192100.0	189872.9	18746.2	43136.5
42	71.19	403135.8	584462.5	192100.0	177953.5	17142.6	39317.5
43	72.88	383366.8	561565.7	190718.3	166801.8	14549.8	38355.9
44	74.58	372845.6	556349.2	187867.1	147174.7	12284.8	36964.1
45	76.27	353424.6	549431.9	185820.9	145495.7	11544.8	32927.6
46	77.97	351180.9	515969.2	177572.6	133295.1	8471.4	26760.0
47	79.66	350264.2	490313.5	172121.9	101335.4	6275.4	23834.3
48	81.36	338134.6	486120.1	171083.1	100337.5	6037.1	19601.3
49	83.05	300237.6	483595.4	157008.0	81320.6	5320.9	19310.3
50	84.75	299050.0	470261.5	154085.8	73573.0	5255.9	17885.4
51	86.44	283035.7	470125.2	150934.0	59227.7	4357.6	16623.7
52	88.14	281920.4	452574.7	133157.7	56494.6	3846.6	12904.0
53	89.83	256718.7	442026.8	127091.2	48354.5	1306.2	11017.8
54	91.53	242535.5	434683.5	112534.2	25609.9	1078.6	10464.1
55	93.22	220529.2	432175.3	97536.2	22746.3	702.6	8975.1
56	94.92	155717.9	418059.6	87138.6	15661.4	550.1	2863.2
57	96.61	102813.0	398847.0	33545.5	6296.7	484.3	1404.1
58	98.31	4614.7	376992.7	31889.5	601.2	118.3	567.6

As discussed in Chapter 5, the skew coefficient is highly uncertain for a small sample size. 58 years is a small sample size. The generalized skew coefficient of −0.2 for central Texas was taken from the Bulletin 17B generalized (Interagency Committee on Water Data 1982) skew map which is reproduced in Wurbs and James (2002) and other references. The −0.2 entered in the *7FFA* record is weighted-averaged (Eqs. 6.13−6.18) with the computed skew coefficient (Equation 6.12) to obtain the adopted values shown in the statistics tables of Table 7.25.

The tables in the *TABLES* output TOU file reproduced as Table 7.24 were developed as specified by the *7FFA* records in the TIN file of Table 7.22 using the data from the AFF file of Table 7.23 which was created with *SIMD*. The likelihood estimates are based on the log-Pearson III distribution as described in Chapter 5. Separate frequency tables are constructed for each of four random variables which consist of peak annual values of (1) naturalized flow, (2) regulated flow, (3) storage volume, and (4) storage volume adjusted by adding excess flows. The peak storage in each of the 58 years is tabulated in ranked order in the last table of Table 7.24 along with relative frequencies computed with the Weibull formula (Equation 6.19). The reason for using the summation of storage and excess flow in the frequency analysis is discussed below.

<u>Effects of Reservoir Operation Issues on Frequency Analyses</u>

Probability distribution functions, such as the log-Pearson type III, are applicable to homogeneous datasets representing the behavior of a particular phenomenon. The 58 annual peak daily naturalized flow volumes represent a homogeneous data set for which the log-Pearson type III distribution is applicable. However, probability estimates are much less accurate for regulated stream flows and reservoir storage. The annual series of peak regulated flow and peak storage volume reflect the effects of reservoir operations. Reservoir operations differ greatly between conservation pool operations, flood control pool operations, and surcharge operations.

A dataset of maximum annual reservoir storage contents is subject to non-homogeneity associated with switching between regular and emergency flood operations as well as between conservation pool and flood control pool operations. *Emergency operations* refers to situations in which flood waters have completely filled the storage capacity of the flood control pool. In this example, emergency operations of the five flood control reservoirs are modeled simply by allowing outflow to equal inflow whenever the flood control pool storage capacity is exceeded. However, even if *FV/FQ* records are used to model surcharge storage, the nonhomogeneity associated with switching between regular (*FF* record) and emergency surcharge (*FV/FQ* record) flood control operations invalidates the application of the log-Pearson III storage frequency analysis. Flood frequency analyses with variable option 4 selected in *7FFA* record field 2 is designed to approximate a reservoir with infinite flood control storage capacity for purposes of dealing with this non-homogeneity issue as described in the following paragraph.

The term *excess flow* is adopted to refer to the flows that are assumed to instantaneous pass through a full reservoir (excess flows = outflows = inflows). *Excess flows* occur only when the flood control storage capacity is full. *SIMD* records excess flows in the last column of the AFF record. With option 4 entered in *7FFA* record field 2, *TABLES* performs the frequency analyses with the sum of storage plus excess flow. This represents a reservoir with infinite flood control storage capacity with releases controlled only by the regular operating rules based on maximum allowable non-damaging flood levels specified for downstream control points. This modeling approximation is relevant only for purposes of performing frequency analyses using the log-Pearson type III or other probability distribution functions.

Another modeling issue is associated with multiple-reservoir system releases from controlled flood control storage. Multiple-reservoir release decisions may be somewhat arbitrary in actual real-world operations as well as in *SIMD*. The release for a particular day is made in *SIMD* from only one of the system reservoirs unless the flood control pool of that reservoir empties or the release does not consume all available downstream channel capacity. Reservoirs on other tributaries may still have an opportunity to release if channel capacity is available. The choice of reservoir for multiple-reservoir release decisions is based on balancing the flood control storage contents as a percent of capacity in accordance with Equation 5.4. The reservoir with *FR* record listed first in the DAT file is considered first if the Eq. 5.4 rank index is the same for all reservoirs in a particular day. An example of this situation is a day in which all reservoirs are at top of conservation pool (bottom of flood control pool) at the beginning of the day. Thus, the order that the reservoirs are listed in the DAT file may affect the allocation of flood waters between the different flood control pools of a multiple-reservoir system.

A relatively large release from the reservoir selected in a particular day may significantly affect the allocation of stored flood waters between the multiple reservoirs. Though not applied in this example, a mechanism for improving the preciseness of the allocation of releases and resulting storage contents between reservoirs is to assign multiple *FR* records to each reservoir that specify different bottom of flood control pool levels and different priorities.

Annual Flood Frequency Analysis with HEC-SSP

The HEC-SSP Statistical Software Package is briefly described in the preceding Chapter 6 and documented in detail by an user manual (Hydrologic Engineering Center 2010). Frequency analysis of annual maximum flows based on Bulletin 17B procedures is one of the several components of HEC-SSP. The *TABLES 7FFA* record and HEC-SSP apply the same methodology, described in Chapter 6, for computing peak annual flows associated with specified exceedance frequencies following procedures outlined in Bulletin 17B of the Interagency Committee on Water Data (1982). The results obtained with HEC-SPP versus the *TABLES 7FFA* routine compare closely, typically within about three significant figures. Differences in results are due primarily to linear interpolation of nonlinear probability tables in the computer programs. Although the basic frequency analysis computations are essentially the same, HEC-SSP provides additional auxiliary information including expected probability adjustments, confidence limits, and the frequency plots illustrated by Figures 7.20, 7.21, and 7.22.

The flood frequency analysis table reproduced as Table 7.25 and the graphs of Figures 7.20, 7.21, and 7.22 are copied directly from the HEC-SSP results. Frequency analyses are performed with HEC-SSP for the 58 annual maxima of annual naturalized flow, regulated flow, and storage contents recorded by *SIMD* in the AFF file for control point WacoL. The frequency analysis results for naturalized flows are tabulated in Table 7.25 and plotted in Figure 7.20. The frequency analyses results for regulated flows and storage contents are presented graphically in Figures 7.21 and 7.22.

The HEC-SSF computed curve tabulated in the first column of Table 7.25 and plotted in the graphs corresponds to the quantities computed by the *TABLES 7FFA* record and represent median values of the random variable. HEC-SSP also includes an expected probability adjustment representing expected (mean) values of the random variable associated with specified exceedance frequencies. Table 7.25 and Figures 7.20, 7.21, and 7.22 also include the 5% and 95% confidence limits for the computed frequency curve. There is a 90% probability that the estimated quantities based on a given sample size (58 years) fall within the 5% and 95% confidence limits, assuming no measurement or computational errors, perfect homogeneity over time, and a perfect fit to the log-Pearson III distribution. The 58 points computed with the Weibull formula (Equation 6.17) are also included on the plots and can be tabulated as well.

Figure 7.20 indicates that the log-Pearson type III probability distribution provides a reasonably good fit for the 1940-1996 annual series of 58 peak naturalized flows at control point WacoL. The plot of regulated flows in Figure 7.21 shows the deviation of high flows from the log-Pearson III distribution due to flood control reservoir operations. Figure 7.22 demonstrates that the log-Pearson III distribution is not a close fit for the 1940-1996 annual series of 58 peak storage volumes in Lake Waco. The maximum storage contents are near the conservation storage capacity in many of the years, which contorts the frequency curve.

Table 7.25
Flood Frequency Table for Naturalized Flow at Control Point WacoL
Developed with the HEC-SSP Statistical Software Package

Computed Curve FLOW, cfs	Expected Probability FLOW, cfs	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, cfs	Confidence Limits 0.95 FLOW, cfs
41,570	45,627	0.2	65,689	29,329
34,132	36,716	0.5	52,252	24,620
28,846	30,605	1.0	43,003	21,192
23,861	24,984	2.0	34,548	17,883
17,742	18,294	5.0	24,594	13,691
13,473	13,743	10.0	17,989	10,650
9,507	9,610	20.0	12,177	7,702
4,650	4,650	50.0	5,658	3,830
2,131	2,103	80.0	2,627	1,669
1,380	1,344	90.0	1,755	1,026
951	910	95.0	1,251	671
456	414	99.0	650	287

Systematic Statistics

Log Transform: FLOW, cfs		Number of Events	
Mean	3.648	Historic Events	0
Standard Dev	0.387	High Outliers	0
Station Skew	-0.349	Low Outliers	0
Regional Skew	-0.200	Zero Events	0
Weighted Skew	-0.309	Missing Events	0
Adopted Skew	-0.309	Systematic Events	58

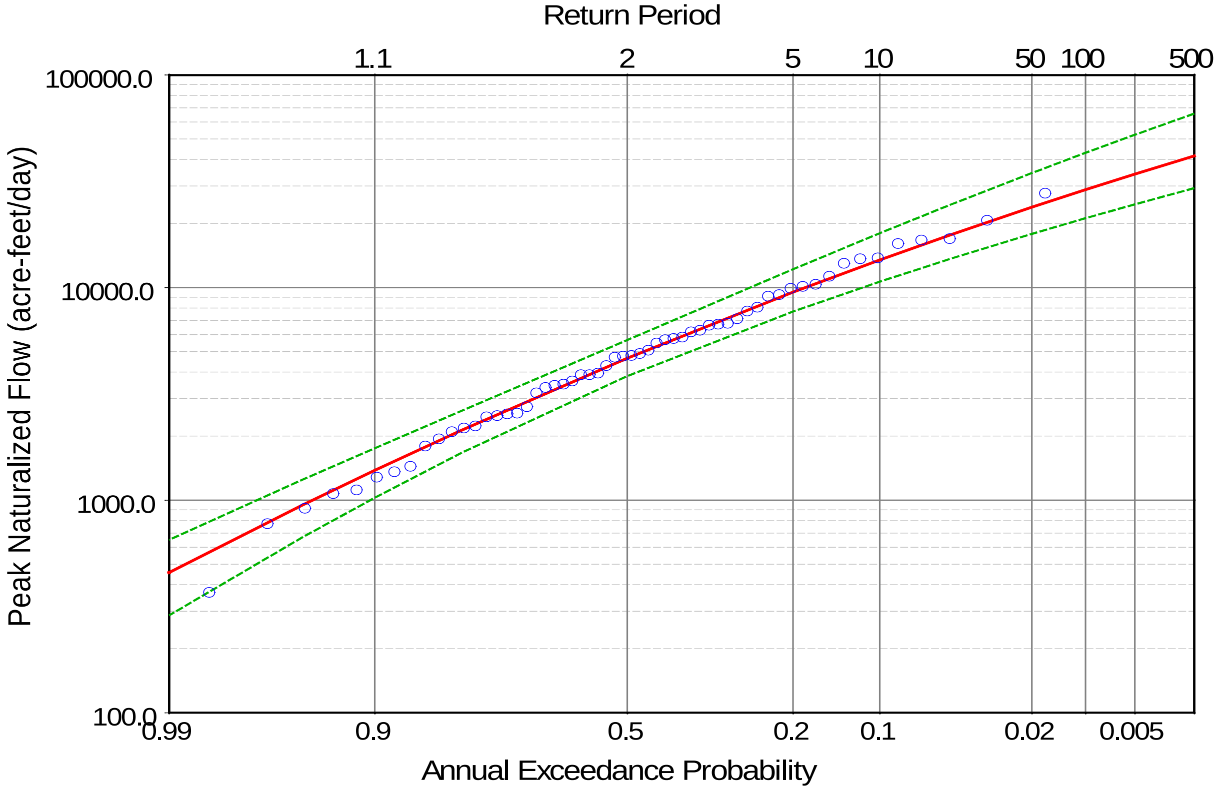

Figure 7.20 Frequency Curve for Maximum Annual Naturalized Flow at Control Point WacoL

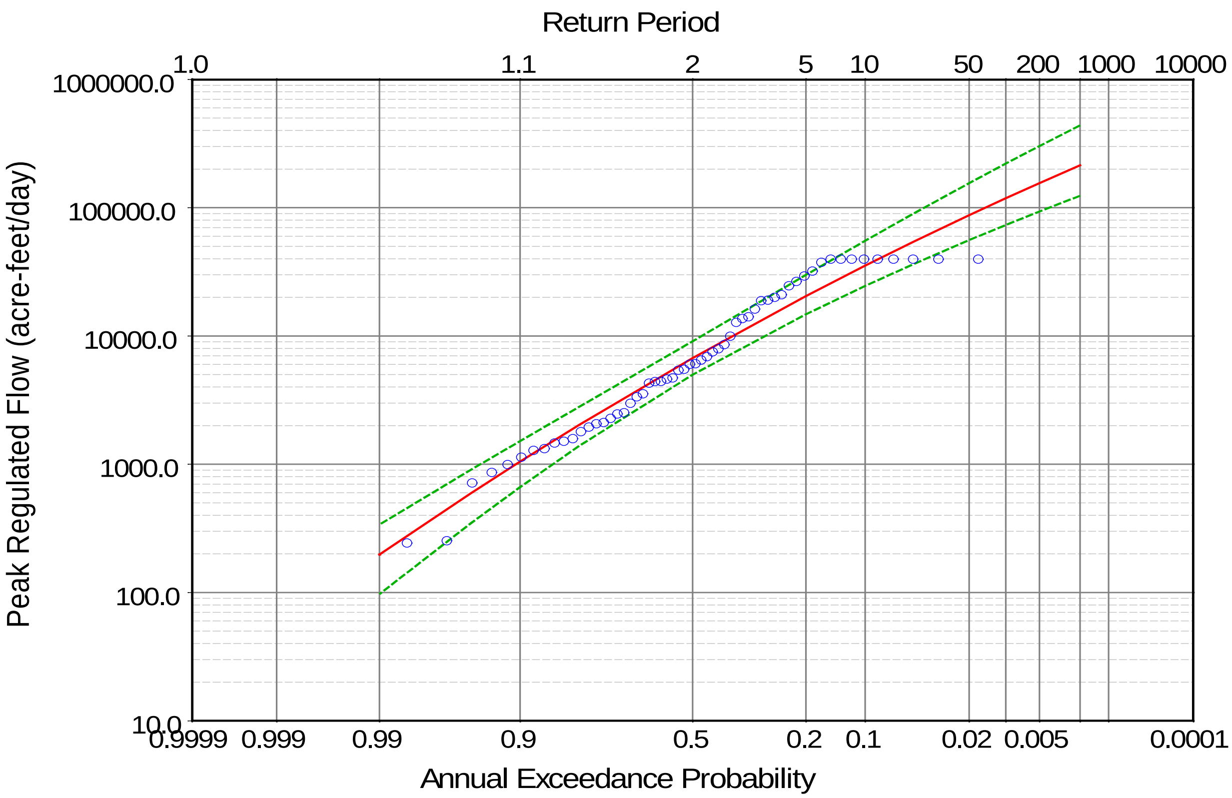

Figure 7.21 Frequency Curve for Maximum Annual Regulated Flow at Control Point WacoL

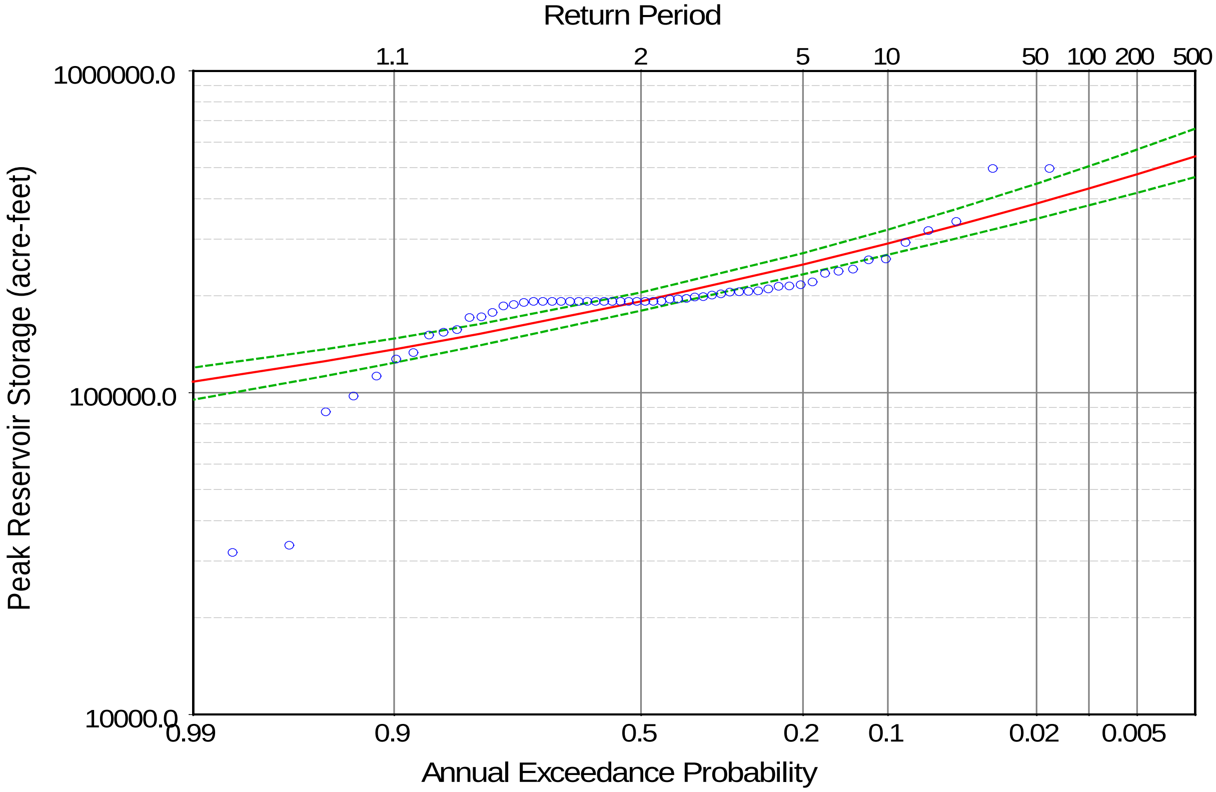

Figure 7.22 Frequency Curve for Maximum Annual Storage Contents of Waco Reservoir

Example 7.3 DATA and 6FRE Analyses of Annual Maximum Storage

Examples 7.3 and 7.4 apply *TABLES* using the *SIMD* output SUB file created in Example 7.2 as input. Selected DATA and 6FREQ record features of *TABLES* are combined in Examples 7.3 and 7.4. In Example 7.3, a 6FRE record is applied to an annual series of maximum daily storage volumes developed with a DATA record from the *SIMD* results of Example 7.2. In Example 7.4, 6FRE records are applied to an annual series of minimum 7-day naturalized flow volumes developed with a DATA record, and the results are used in Example 7.5. Although DATA record capabilities also include features for developing monthly and daily datasets, Examples 7.3 and 7.4 focus on developing annual series of daily data.

Program *TABLES* provides flexible capabilities for performing frequency analyses for an extensive range of variables including all the *SIMD* simulation results variables and various transformations thereof. A DATA record can be used to organize *SIMD* or *SIM* simulation results and manipulate the simulation results to create other data series. 6FRE and 6FRQ records can be used to perform frequency analyses of data series created with a DATA record. Time series records also treat data series created with a DATA record in the same manner as *SIMD* or *SIM* simulation results. A DATA record works with any of the simulation results variables.

TABLES Input TIN File for Example 7.3

Example 7.3 consists of applying a DATA record to develop annual series of maximum storage volume for each of the six reservoirs and performing 6FRE record frequency analyses. The results are compared with 7FFA flood frequency analysis methods applied in Example 7.2. The *TABLES* input TIN file is reproduced as Table 7.26.

Table 7.26
TABLES Input TIN File for Example 7.3

```
**      1       2       3       4       5
**  5678901234567890123456789012345678901234567890012
**      !   !   !   !   !   !   !   !   !   !   !   !
DATA6STO   0   6   1   0   0   3               4
IDEN      PK    Whit   WacoL  Belton  George   Grang
6FRE  11   0  -6   2   2
7FFA   3   2   1   6   6
IDEN      PK    Whit   WacoL  Belton  George   Grang
ENDF
```

A DATA record instructs *TABLES* to read either a *SIM* or *SIMD* monthly simulation results output OUT file or *SIMD* sub-monthly (daily) simulation results output SUB file. In Example 7.3, 2STO in DATA record field 2 means that end-of-day storage volumes are read from a SUB file generated by *SIMD*. This is the SUB file produced in Example 7.2.

TABLES creates a monthly or sub-monthly (daily) data array and/or an annual series data array. Option 1 in column 20 of the DATA record of Table 7.26 indicates that an annual data array is created. This array stored in computer memory is accessed by the 6FRE record and is also optionally tabulated in the *TABLES* output TOU file.

The *SIMD* simulation results may be transformed by applying an equation defined by addition XF and addition AF factors entered in DATA record fields 14 and 15 or by computing moving averages or moving totals over any number of time periods. These options are not applied in Example 7.3. The moving totals option is applied in Example 7.4.

For an annual series, alternative options specified in DATA record column 32 include annual or seasonal totals each year, the minimum each year, or maximum amount in each year. Option 3 in this example means the maximum of the 365 or 366 end-of-day storage volumes in each year is adopted.

The DATA record provides options to work with the *SIM* or *SIMD* simulation results for the entire year each year or alternatively to work with data for only a specified season of the year as defined in fields 9, 10, 11, and 12. Examples 7.3 and 7.4 work with all of the data without limiting the analysis to a specified season.

TABLES Output TOU File for Example 7.3

The main purpose of the DATA record is to create a data array that is stored in computer memory to be accessed by any number of frequency and time series records that follow in the TIN file. However, the array can also be written in the TOU file. The first table in the TOU output file of Table 7.27 is an optional tabulation of the annual data series array activated by option 4 entered in column 52 of the DATA record. Option 4 includes columns with the month and day of each of the amounts. Since the same amounts can be repeated in multiple days of a year, the date represents the first day of that year that the amount occurred which is likely but not necessarily the only day. The maximum end-of-day storage volumes are in units of acre-feet.

The same annual series of 58 maximum end-of-day storage contents of each of the six reservoirs are tabulated in both the last table of Table 7.24 and the first table of Table 7.27. However, these two tables created by 7FFA and DATA records are organized differently. The 7FFA and DATA tables list the volumes in rank order and chronological order, respectively.

The 6FRE record in Table 7.26 performs frequency analyses for the 58-year annual series of maximum end-of-day storage volume of each of the six reservoirs. Option 11 in 6FRE record field 11 indicates that the analysis is for an annual series data array created by the preceding DATA record. The entry of 2 in column 20 selects the option of organizing the frequency table in columns to allow more digits beyond the decimal point and more frequencies. Option 2 for parameter METHOD in column 24 activates the log-normal probability distribution methodology for performing the frequency analysis rather than the default relative frequency (Eq. 6.3) option.

7FFA record flood frequency analyses based on the log-Pearson III distribution are presented in the preceding Example 7.2. A 7FFA record is included in the TIN file for Example 7.3 for comparison. The 7FFA record of Table 7.25 creates the flood frequency analysis and accompanying statistics tables in Table 7.27. The log-normal probability distribution option is adopted on both the 7FFA and 6FRE records. The 7FFA record automatically applies the log-Pearson type III probability distribution. However, with a skew coefficient of zero (option 6) specified in 7FFA column 24, log-Pearson III becomes identical to the log-normal distribution. The Weibull formula (Eq. 6.17) is not used here but provides a relative frequency based alternative option. The 6FRE and 7FFA records in Table 7.26 produce the same values for the frequency metrics though the resulting frequency tables in Table 7.27 are organized differently. Tables 7.24 and 7.27 provide statistics for peak storage and the logarithms of peak storage.

Table 7.27
TABLES Output TOU File for Example 7.3

DATA RECORD VARIABLE 6STO ANNUAL SERIES DATASET

YEAR	PK		Whit		WacoL		Belton		George		Grang	
1940	596776.56	6/28	712170.38	12/11	241868.53	12/17	608337.81	12/20	59620.39	12/20	114922.23	12/17
1941	665540.00	10/10	957343.44	5/14	216465.45	5/ 2	553328.44	5/28	50432.41	6/22	97861.83	6/20
1942	610392.62	4/27	1038785.62	5/ 1	260157.58	5/ 2	591217.00	6/ 2	43605.37	6/10	82796.09	6/ 5
1943	571319.00	5/ 2	612114.69	1/ 3	192100.00	1/ 1	457600.00	1/17	36889.57	1/29	65500.00	1/ 1
1944	256718.66	11/ 4	613976.19	5/31	205213.48	5/ 5	841072.12	5/16	55833.01	5/18	109279.77	5/16
1945	543749.69	10/30	661726.88	4/29	318715.78	4/10	720520.81	4/10	50440.01	4/28	91832.42	4/28
1946	577575.88	10/25	627100.00	5/ 3	202725.38	5/ 4	500321.50	5/ 4	39619.32	5/10	71417.53	5/ 4
1947	602242.50	5/25	659833.12	5/ 2	195451.98	5/ 3	461300.44	5/ 2	39677.54	5/ 3	71637.16	5/ 2
1948	350264.16	7/15	515969.25	6/ 8	157008.03	6/ 2	230580.16	1/ 1	19410.87	5/30	38355.93	4/29
1949	425485.09	6/25	627100.00	5/14	190718.30	6/22	177953.47	6/21	6275.44	5/ 6	17885.39	6/23
1950	537202.75	10/ 1	561565.69	5/ 2	171083.08	5/ 7	48354.50	1/ 1	702.57	5/ 8	2863.20	5/ 9
1951	283035.69	1/ 1	490313.50	6/21	112534.16	1/ 1	6296.70	6/24	484.25	9/16	1404.06	9/15
1952	4614.65	5/31	418059.56	5/29	97536.21	5/30	25609.92	5/15	5255.94	5/15	12904.00	5/13
1953	220529.23	8/ 6	452574.69	5/ 3	150934.05	5/30	101335.37	5/31	8471.37	10/27	19601.25	10/25
1954	403135.78	6/ 6	376992.69	1/ 1	87138.60	1/ 1	601.17	5/ 2	5320.88	1/ 1	11017.79	1/ 1
1955	604519.50	10/25	398847.00	6/12	31889.54	6/11	59227.66	6/15	3846.64	6/10	8975.06	6/16
1956	433133.97	1/ 1	434683.50	5/ 6	33545.52	5/31	56494.61	5/12	118.34	5/21	567.59	5/21
1957	665540.00	5/30	2000000.00	5/25	292621.38	5/ 6	760540.69	5/30	64407.61	5/ 6	140751.34	5/ 6
1958	593066.56	5/14	670147.50	5/14	198824.81	5/11	510772.44	5/20	42521.36	3/14	76736.06	3/14
1959	490798.88	10/31	627100.00	10/13	192100.00	6/18	485773.34	10/31	44377.45	12/ 9	82168.63	12/ 9
1960	577256.38	7/15	627100.00	1/ 1	192100.00	1/ 1	466613.19	2/ 4	43196.86	12/14	88911.05	12/12
1961	590386.94	6/21	661882.88	2/ 6	258719.09	1/14	574230.75	1/17	57387.56	2/18	102447.50	2/18
1962	610980.06	9/13	627100.00	9/17	192100.00	1/ 1	457599.97	1/ 1	32343.40	6/ 5	65500.00	1/ 1
1963	579416.88	6/ 7	607121.25	1/ 2	172121.86	1/ 1	339251.53	1/ 1	20626.28	1/ 1	43136.55	1/ 1
1964	102812.95	2/13	470125.22	1/ 1	133157.69	6/29	73573.00	1/ 1	1306.15	5/ 3	10464.06	3/28
1965	412941.91	6/20	713846.31	5/23	340190.41	5/21	728766.25	5/31	63196.34	5/31	143839.89	5/30
1966	596062.25	5/ 4	633032.69	5/ 5	220707.00	4/29	458271.12	5/ 2	44508.07	5/ 8	106860.97	4/30
1967	451781.91	1/ 1	598762.31	1/ 1	177572.59	1/ 1	362526.47	1/ 1	24805.00	1/ 1	51497.17	1/ 1
1968	576748.69	6/16	821370.69	5/15	238279.30	5/21	566481.31	5/19	48981.08	5/24	106732.42	1/24
1969	599393.56	5/12	689795.69	5/ 8	192100.00	1/ 1	457600.00	5/ 8	42308.21	5/ 4	81926.71	4/15
1970	581755.00	5/ 7	627540.44	4/29	192100.00	2/ 5	468441.66	5/ 3	40644.50	5/ 3	74327.15	5/ 2
1971	300237.62	9/20	584462.50	12/29	192100.00	12/13	189872.92	1/ 1	14549.81	1/ 1	26760.04	1/ 1
1972	281920.44	1/ 1	623955.56	1/31	192100.00	1/ 1	145495.72	2/28	1078.57	1/ 1	16623.75	5/19
1973	299050.03	6/29	742216.56	4/30	200992.58	10/29	147174.66	7/ 4	31072.21	7/14	67633.34	10/29
1974	540653.75	12/15	607853.81	1/ 1	198207.67	10/ 1	235020.47	12/31	37100.00	5/11	65500.00	1/ 1
1975	579248.75	6/28	677765.69	5/21	206256.44	5/22	525993.75	5/27	59152.84	5/24	103011.95	5/24
1976	468648.62	12/ 5	549431.94	7/ 4	192100.00	6/10	402772.16	7/24	37100.00	5/22	70361.62	4/30
1977	575893.19	5/30	698746.12	4/18	234653.86	4/15	621465.00	4/30	82052.28	5/ 4	108120.44	4/25
1978	589315.00	8/23	442026.75	8/10	127091.19	1/ 1	166801.80	1/ 1	12284.76	1/ 1	23834.31	1/ 1
1979	338134.62	7/ 9	630590.62	5/30	196153.19	5/31	306704.91	7/ 5	40331.82	5/ 9	84971.50	5/ 8
1980	353424.56	11/ 2	486120.12	5/ 7	187867.12	5/ 7	265459.25	5/29	24678.43	5/29	50107.55	5/16
1981	626673.12	10/13	861899.69	10/12	207135.38	6/25	133295.06	6/30	76440.38	6/27	142147.31	6/25
1982	628332.62	6/16	809110.44	6/21	192308.06	7/31	100337.47	7/ 8	37100.00	6/ 6	68482.75	5/ 2
1983	242535.55	6/12	556349.25	1/ 1	192100.00	2/14	22746.35	3/29	37100.00	6/ 9	65500.00	5/22
1984	155717.92	12/31	432175.31	12/17	154085.81	12/30	15661.43	10/17	4357.62	12/29	19310.29	12/29
1985	508270.16	6/28	483595.38	6/11	192100.00	12/14	81320.62	6/13	33437.42	4/24	65500.00	3/14
1986	598493.56	10/29	601631.56	12/31	192100.00	1/ 1	401897.88	12/31	37100.00	2/20	76877.48	12/19
1987	601105.25	6/ 5	696420.31	6/16	209849.62	6/17	663661.00	6/26	53644.66	6/30	91395.06	5/ 5
1988	383366.78	1/ 1	470261.50	1/ 1	185820.88	6/28	296563.31	1/ 1	22433.53	1/ 1	46433.88	2/ 9
1989	372845.59	7/ 3	627100.00	5/11	192100.00	4/ 5	194678.48	6/28	11544.77	6/13	32927.64	6/23
1990	646128.31	4/30	1513586.88	5/ 8	213966.41	5/ 4	469357.91	6/29	550.15	5/ 4	39317.52	5/31
1991	606114.44	12/12	1430604.00	12/29	496834.03	12/31	865370.69	12/31	55966.13	12/31	148931.70	12/31
1992	614414.19	6/16	1404023.38	1/ 1	496931.53	1/ 2	1091320.00	2/14	130800.00	2/28	244200.00	2/19
1993	574086.44	5/ 3	679042.50	5/ 4	195188.77	5/ 5	472061.09	6/ 7	39161.08	6/ 9	80006.83	2/22
1994	563790.88	5/24	627100.00	5/26	192100.00	2/26	380923.09	6/22	18746.22	1/ 1	46129.03	12/30
1995	470992.53	9/ 9	699467.38	5/20	205904.94	5/22	522904.44	5/23	17142.60	6/11	75424.52	5/26
1996	351180.88	1/ 1	611034.00	12/31	192100.00	12/17	286484.62	1/ 1	6037.14	12/31	36964.09	1/ 1
1997	588004.75	6/ 5	658867.69	4/15	214600.88	4/16	658154.69	6/25	77816.58	5/ 6	185659.98	5/ 6

Table 7.27 Continued
TABLES Output TOU File for Example 7.3

VARIABLE 6STO IN DATA RECORD DATASET
Daily Data Ranging From January 1940 through December 1997
DATA Record Parameters DR(1-10) 0 6 1 0 0 3 1 1 12 31

CP	PK	Whit	WacoL	Belton	George	Grang
Mean	482306.12	685164.12	201905.69	376105.03	34403.32	70280.23
Std Dev	154335.25	284900.94	76989.08	252413.17	25392.19	47441.16
Minimum	4614.65	376992.69	31889.54	601.17	118.34	567.59
99.5%	67886.11	284497.34	60046.50	7435.04	447.20	2623.00
99%	81128.06	308032.78	67020.72	10397.20	645.14	3479.00
98%	98569.05	335983.59	75571.39	14998.84	962.88	4736.83
95%	132006.25	382736.22	90485.65	25987.89	1755.69	7525.57
90%	171121.47	429707.09	106189.27	42351.54	2993.90	11354.68
85%	203866.44	464610.97	118295.96	58879.32	4291.56	14986.22
80%	234308.56	494366.31	128896.45	76507.36	5713.67	18684.77
75%	264018.41	521403.62	138742.81	95778.27	7303.59	22576.61
70%	293900.09	546945.56	148226.09	117191.03	9105.39	26758.46
60%	356688.03	596280.62	167023.05	168706.52	13558.95	36369.16
50%	427450.28	646409.56	186742.06	237156.91	19672.58	48450.95
40%	512250.84	700752.81	208789.12	333380.09	28542.81	64546.28
30%	621686.56	763961.44	235266.25	479929.16	42503.45	87729.04
25%	692024.94	801373.19	251341.27	587185.69	52985.25	103973.11
20%	779799.62	845214.00	270547.38	735137.00	67734.15	125636.78
15%	896242.38	899344.50	294791.09	955231.75	90179.47	156643.52
10%	1067742.88	972395.69	328400.41	1328013.00	129266.49	206742.47
5%	1384109.62	1091725.88	385390.31	2164155.75	220425.44	311928.66
2%	1853636.00	1243639.75	461448.31	3749745.50	401917.53	495571.72
1%	2252132.25	1356487.38	520321.06	5409334.00	599864.69	674746.56
0.5%	2691474.75	1468714.38	580759.88	7564643.50	865405.44	894967.00
Maximum	665540.00	2000000.00	496931.53	1091320.00	130800.00	244200.00

FLOOD FREQUENCIES FOR RESERVOIR STORAGE

CONTROL POINT	ANNUAL RECURRENCE INTERVAL (YEARS) AND EXCEEDANCE FREQUENCY (%) 1.01 99%	2 50%	5 20%	10 10%	25 4%	50 2%	100 1%	200 0.5%	500 0.2%	EXPECTED VALUE
PK	81129.	427450.	779799.	1067734.	1492810.	1853632.	2252125.	2691469.	3340268.	557368.
Whit	308035.	646410.	845214.	972394.	1129170.	1243640.	1356487.	1468714.	1617232.	664705.
WacoL	67021.	186742.	270547.	328399.	403783.	461449.	520321.	580760.	663487.	202521.
Belton	10398.	237157.	735135.	1327988.	2495021.	3749717.	5409286.	7564569.	11357484.	616168.
George	645.	19672.	67735.	129267.	257512.	401929.	599884.	865438.	1349341.	60833.
Grang	3479.	48451.	125637.	206740.	351636.	495569.	674742.	894960.	1260246.	96225.

STATISTICS FOR PEAK ANNUAL RESERVOIR STORAGE

CONTROL POINT	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	Statistics for Logarithms of Annual Peaks: MEAN	STANDARD DEVIATION	INPUT SKEW	COMPUTED SKEW	ADOPTED SKEW
PK	482306.	154335.	4615.	665540.	5.6309	0.3102	0.0000	-4.8061	0.0000
Whit	685164.	284901.	376993.	2000000.	5.8105	0.1384	0.0000	1.4096	0.0000
WacoL	201906.	76989.	31890.	496932.	5.2712	0.1913	0.0000	-1.9301	0.0000
Belton	376105.	252413.	601.	1091320.	5.3750	0.5838	0.0000	-2.2094	0.0000
George	34403.	25392.	118.	130800.	4.2939	0.6380	0.0000	-1.6833	0.0000
Grang	70280.	47441.	568.	244200.	4.6853	0.4917	0.0000	-1.9457	0.0000

Example 7.4 DATA and 6FRE Analyses of Annual 7-Day Minimum Flow

The DATA and 6FRE records are used in Example 7.4 to develop frequency metrics for annual minimum 7-day naturalized flow volumes. The results are used in Example 7.5 to set building instream flow targets. *TABLES* acquires daily naturalized flows from the *SIMD* output SUB file of either Example 7.1 or 7.2, which contain the same naturalized flows. The DATA record provides capabilities for developing an annual series of minimum 7-day flow volumes. Low-flow frequency analyses are performed with a 6FRE record.

The TIN file in Table 7.28 below begins with a DATA record. 6NAT in DATA record field 2 means that daily naturalized flows are read from a SUB file generated by *SIMD*. Option 1 in column 20 of the DATA record of Table 7.28 indicates that an annual data array is created. Entries in columns 24 and 28 specify 7-day moving totals. Option 2 in column 32 means the minimum of the 365 or 366 seven-day volumes in each year is adopted. The three 6FRE records in the TIN file below illustrate two alternative methods (relative frequency versus probability distribution) for performing the frequency analysis of the data provided by the DATA record and two options for organizing the results of the frequency analysis (row-based table versus column-based table).

Table 7.28
TABLES Input TIN File for Example 7.4

```
**       1         2         3         4         5
**  5678901234567890123456789012345678901234567890112
**     !   !   !   !   !   !   !   !   !   !   !   !
DATA6NAT   0   0   1   2   7   2                   1
6FRE  11   0   0   2
6FRE  11   0   0   1
6FRE  11   0   0   1   2
ENDF
```

The monthly naturalized flows in the FLO file from the *Fundamentals Manual* example are adopted the same in Examples 7.1, 7.2, and 7.5 along with the same flow disaggregation options. Thus, the same daily naturalized flows are obtained from either Examples 7.1 or 7.2.

In accordance with the DATA record in the TIN file of Table 7.28, the *TABLES* routines governed by the DATA record

- read the 21,185 daily naturalized flows at each of the eleven control points from the *SIMD* output SUB file of Example 7.1 or Example 7.2
- compute 21,185 seven-day moving totals
- record the minimum of the 365 or 366 seven-day moving totals in each of the 58 years in an array which is accessed by the 6FRE records

The 7-day moving totals are the summation of daily flow volumes for the current day and six preceding days. Since seven days are required for 7-day summation, the first six days of the first year (1940) are not considered in the selection of the minimum 7-day volume for 1940. The

DATA record produces annual series for each of the 11 control points consisting of the minimum 7-day volume of naturalized flow in each of the 58 years of the simulation tabulated below.

Table 7.29
TABLES Output TOU File for Example 7.4

DATA RECORD VARIABLE 6NAT ANNUAL SERIES DATASET

YEAR	PK	Whit	WacoL	WacoG	High	Belton	George	Grang	Camer	Bryan	Hemp
1940	3.70	74.44	0.00	167.76	210.91	0.00	18.00	57.88	168.92	676.18	1009.80
1941	76.55	3258.00	53.25	6530.06	7398.09	1207.66	35.06	112.83	2661.41	11740.76	5944.46
1942	271.56	701.44	124.69	1324.41	1615.87	0.00	57.61	185.42	2037.55	2531.76	2420.14
1943	2.17	122.24	2.11	237.50	356.95	0.00	1.93	6.27	145.89	1275.32	3259.41
1944	5.84	580.84	1.61	815.79	1360.03	0.00	8.27	26.56	69.57	2884.63	4337.76
1945	26.90	652.98	52.89	940.41	1378.12	273.89	43.15	138.81	964.45	4016.41	8339.10
1946	70.91	251.78	0.00	767.74	1137.80	23.29	98.19	316.14	501.74	3008.50	3277.20
1947	64.21	720.22	0.00	1163.96	1429.93	1.23	8.58	27.66	104.78	1986.72	5112.76
1948	41.82	405.83	0.00	653.43	740.78	0.00	7.69	24.77	147.00	1259.66	1394.37
1949	1.35	341.68	5.49	737.42	843.74	43.88	4.29	13.81	292.59	1780.88	4087.72
1950	16.06	351.47	22.72	268.35	258.02	0.00	0.77	2.48	75.64	172.31	813.25
1951	0.00	117.74	14.68	127.18	172.22	0.00	4.34	13.86	43.13	402.83	1055.53
1952	0.25	0.00	0.00	84.05	211.21	0.00	1.77	5.80	1.41	116.72	248.88
1953	0.00	0.00	0.00	81.54	801.02	0.00	25.09	80.75	326.27	3695.98	6415.33
1954	0.00	0.00	1.12	56.72	133.76	0.00	0.04	0.14	1.63	98.66	220.99
1955	47.83	6.49	0.00	61.95	255.85	0.00	2.62	8.45	91.03	274.68	770.20
1956	0.00	101.31	0.00	173.05	176.24	0.00	0.00	0.00	0.00	0.00	200.88
1957	0.00	655.10	0.00	541.84	489.59	44.17	27.50	88.51	553.53	368.36	976.43
1958	0.00	679.72	41.00	1098.13	1964.49	49.95	111.32	358.16	1137.29	3769.04	5258.93
1959	0.65	38.75	5.51	158.54	198.19	138.24	37.48	120.61	1290.92	1896.47	3646.27
1960	0.00	470.44	5.63	587.37	903.24	0.00	40.91	131.68	557.47	2322.10	2999.76
1961	34.46	2481.06	147.39	4006.08	4796.48	896.33	84.03	270.44	4769.55	13781.86	16166.04
1962	24.63	722.06	0.54	2123.63	2851.59	0.00	11.46	36.81	482.06	3530.97	3336.66
1963	0.00	318.95	0.00	0.00	209.46	0.00	2.94	9.52	105.65	1134.07	2444.17
1964	2.33	331.56	9.14	646.58	901.39	0.00	5.45	17.57	136.22	1696.39	2814.31
1965	9.82	839.27	95.65	2318.64	2640.59	493.00	80.81	260.00	2021.87	7801.77	6999.21
1966	11.53	499.14	40.83	2076.03	2732.25	372.01	151.33	672.89	2687.27	6315.47	9417.33
1967	7.79	1375.43	31.36	2419.23	2924.51	3.24	11.17	32.76	201.14	6070.30	5574.99
1968	0.00	1025.54	147.84	1943.43	2674.55	159.09	36.40	497.14	2008.10	6818.69	10994.49
1969	92.92	584.43	12.72	1427.31	1388.30	19.42	63.89	220.88	1425.90	8076.25	10883.39
1970	0.00	153.42	50.09	115.85	146.88	0.00	1.91	26.36	448.56	836.47	2075.70
1971	0.57	537.39	182.00	596.79	619.47	57.03	1.25	17.86	245.16	1779.89	2206.50
1972	98.03	283.67	118.69	602.76	669.57	0.00	4.94	44.35	34.05	2061.03	1775.48
1973	0.00	1431.61	7.75	2263.15	4039.68	0.00	50.26	317.10	734.71	11947.90	17534.96
1974	11.06	988.51	10.36	737.11	1304.18	0.00	68.04	115.26	269.15	1748.20	2922.36
1975	68.85	96.26	33.64	277.29	461.31	0.00	26.06	137.54	683.21	2742.11	3347.92
1976	225.42	590.14	0.00	1256.52	2664.87	59.75	49.34	344.29	1428.76	3787.75	4582.72
1977	0.00	0.00	0.00	450.38	772.59	0.00	1.92	29.42	117.69	1292.30	2909.14
1978	7.13	72.38	0.00	123.69	181.72	0.00	0.89	0.00	116.97	392.61	1547.54
1979	0.00	65.13	12.48	0.00	147.47	0.00	14.58	125.37	438.32	2276.27	5847.75
1980	116.29	148.66	2.23	130.84	308.97	0.00	0.32	0.00	111.89	1486.68	2012.28
1981	280.39	741.76	22.90	330.87	1006.20	20.43	69.12	0.00	879.20	1802.68	4098.82
1982	2.63	0.00	0.00	64.86	182.39	0.00	0.00	0.00	13.09	231.71	389.64
1983	0.00	0.00	18.45	330.75	519.43	0.00	0.00	0.98	59.55	2167.32	5093.32
1984	0.00	0.00	52.77	314.56	361.40	0.00	0.00	0.00	3.22	370.46	607.60
1985	1.07	549.92	0.00	1080.47	686.72	0.00	0.00	0.00	110.28	1657.05	2217.59
1986	130.91	209.07	0.00	447.66	551.80	112.96	0.00	75.51	856.18	2382.21	3449.73
1987	179.93	803.36	0.00	0.00	248.38	1.35	7.96	103.77	539.98	2701.34	4859.72
1988	8.87	0.00	0.00	89.69	796.41	14.58	0.00	0.00	303.18	1651.13	1454.32
1989	7.12	372.92	0.00	664.60	987.78	0.00	0.00	0.00	241.17	1460.42	1877.27
1990	38.20	275.35	0.00	377.41	516.59	0.00	0.00	0.00	270.81	1014.94	1883.13
1991	58.48	1523.60	133.91	1624.39	2968.15	274.27	27.43	239.05	1547.45	5347.37	6160.06
1992	66.91	614.54	0.00	632.17	837.28	0.00	3.75	82.02	439.14	1539.24	2010.80
1993	297.69	981.31	0.00	950.14	1910.89	0.00	0.01	2.66	361.87	5122.58	8960.63
1994	129.26	903.66	0.00	0.00	1566.42	0.00	0.34	0.00	22.50	1622.23	2022.09
1995	98.24	472.95	0.00	1055.54	1182.46	161.74	0.00	23.30	553.28	2095.87	4457.21
1996	93.02	150.78	0.00	327.79	490.01	110.64	10.95	0.00	496.49	1957.84	2656.48
1997	0.00	515.11	0.00	708.33	1009.02	11.84	0.00	63.85	431.69	2261.65	3281.18

Table 7.29 Continued
TABLES Output TOU File for Example 7.4

```
VARIABLE 6NAT IN DATA RECORD DATASET
Daily Data Ranging From January 1940 through December 1997
DATA Record Parameters DR(1-10)  0  0  1  2  7  2  1  1 12 31
```

CP	PK	Whit	WacoL	WacoG	High	Belton	George	Grang	Camer	Bryan	Hemp
Mean	47.13	520.51	25.20	846.41	1211.95	78.45	22.78	94.61	633.92	2848.98	4011.41
Std Dev	74.44	592.13	44.97	1091.97	1324.24	211.39	32.93	137.38	863.66	2958.43	3551.77
Minimum	0.00	0.00	0.00	0.00	133.76	0.00	0.00	0.00	0.00	0.00	200.88
99.5%	0.00	0.00	0.00	0.00	137.56	0.00	0.00	0.00	0.41	28.61	206.71
99%	0.00	0.00	0.00	0.00	141.37	0.00	0.00	0.00	0.82	57.22	212.54
98%	0.00	0.00	0.00	0.00	146.97	0.00	0.00	0.00	1.45	101.55	225.45
95%	0.00	0.00	0.00	0.00	169.75	0.00	0.00	0.00	3.06	166.75	375.56
90%	0.00	0.00	0.00	64.28	182.26	0.00	0.00	0.00	31.74	349.62	804.64
85%	0.00	29.07	0.00	88.00	210.47	0.00	0.00	0.00	66.56	399.76	1041.81
80%	0.00	73.62	0.00	125.78	252.86	0.00	0.03	0.08	99.28	943.55	1510.25
75%	0.00	109.52	0.00	163.15	332.96	0.00	0.56	2.57	111.08	1267.49	1880.20
70%	0.60	149.51	0.00	249.84	472.62	0.00	1.46	7.14	125.10	1470.92	2016.20
60%	2.84	290.73	0.00	340.18	629.49	0.00	3.10	18.95	241.97	1706.75	2486.63
50%	8.87	405.83	2.11	596.79	801.02	0.00	7.69	29.42	326.27	1957.84	3259.41
40%	26.45	547.41	8.86	699.58	1002.52	1.33	11.40	73.18	475.36	2273.35	3606.96
30%	61.92	654.25	21.01	946.25	1370.88	22.15	27.47	114.29	555.89	2827.62	4748.92
25%	69.88	710.83	32.50	1089.30	1498.18	47.06	36.94	128.53	795.44	3613.48	5185.85
20%	92.96	766.40	44.64	1283.68	1932.33	80.11	45.63	157.45	1033.59	3879.21	5886.43
15%	103.65	926.95	53.00	1720.10	2667.77	144.49	59.49	245.33	1426.76	5564.25	6590.49
10%	140.71	1095.52	119.89	2151.53	2866.17	273.97	71.46	316.33	2010.85	7015.31	9051.97
5%	272.44	1619.35	147.43	2577.92	4115.36	533.33	99.50	372.06	2664.00	11761.47	11511.64
2%	294.92	3133.69	176.53	6126.22	6981.83	1157.85	144.93	644.77	4436.39	13488.43	17315.93
1%	297.69	3258.00	182.00	6530.06	7398.09	1207.66	151.33	672.89	4769.55	13781.86	17534.96
0.5%	297.69	3258.00	182.00	6530.06	7398.09	1207.66	151.33	672.89	4769.55	13781.86	17534.96
Maximum	297.69	3258.00	182.00	6530.06	7398.09	1207.66	151.33	672.89	4769.55	13781.86	17534.96

```
VARIABLE 6NAT IN DATA RECORD DATASET
Daily Data Ranging From January 1940 through December 1997
DATA Record Parameters DR(1-10)  0  0  1  2  7  2  1  1 12 31
```

CONTROL		STANDARD	PERCENTAGE OF YEARS WITH VALUES EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	47.13	74.4	0.00	0.00	0.00	0.00	0.00	0.00	2.8	8.9	26.4	69.9	140.7	297.7
Whit	520.51	592.1	0.00	0.00	0.00	0.00	0.00	109.52	290.7	405.8	547.4	710.8	1095.5	3258.0
WacoL	25.20	45.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	2.1	8.9	32.5	119.9	182.0
WacoG	846.41	1092.0	0.00	0.00	0.00	0.00	64.28	163.15	340.2	596.8	699.6	1089.3	2151.5	6530.1
High	1211.95	1324.2	133.76	141.37	146.97	169.75	182.26	332.96	629.5	801.0	1002.5	1498.2	2866.2	7398.1
Belton	78.45	211.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1.3	47.1	274.0	1207.7
George	22.78	32.9	0.00	0.00	0.00	0.00	0.00	0.56	3.1	7.7	11.4	36.9	71.5	151.3
Grang	94.61	137.4	0.00	0.00	0.00	0.00	0.00	2.57	18.9	29.4	73.2	128.5	316.3	672.9
Camer	633.92	863.7	0.00	0.82	1.45	3.06	31.74	111.08	242.0	326.3	475.4	795.4	2010.9	4769.5
Bryan	2848.98	2958.4	0.00	57.22	101.55	166.75	349.62	1267.49	1706.8	1957.8	2273.3	3613.5	7015.3	13781.9
Hemp	4011.41	3551.8	200.88	212.54	225.45	375.56	804.64	1880.20	2486.6	3259.4	3607.0	5185.8	9052.0	17535.0

The HEC-SSP Statistical Software Package available from the USACE Hydrologic Engineering Center is introduced in Chapter 6. The flood frequency analysis component of HEC-SSP is illustrated in Example 7.2. The several different components of HEC-SSP also include volume frequency analysis of the minimum or maximum stream flow volume occurring over any specified number of days in each year of a series of years. The Example 7.4 frequency analysis of annual minimum 7-day low flows could also be performed with HEC-SSP. HEC-SSP reads a DSS file of daily *SIMD* simulation results, performs the frequency computations, and reports the results as tables and graphs. The frequency graphs are in the general format illustrated by Figures 7.20, 7.21, and 7.22. Multiple durations can be plotted on the same graph.

Table 7.29 Continued
TABLES Output TOU File for Example 7.4

```
VARIABLE 6NAT IN DATA RECORD DATASET
Daily Data Ranging From January 1940 through December 1997
DATA Record Parameters DR(1-10)  0  0  1  2  7  2  1  1 12 31
```

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF YEARS WITH VALUES EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
PK	47.13	74.4	0.00	0.00	0.00	0.00	0.02	0.20	1.0	2.6	6.8	33.6	338.2	297.7
Whit	520.51	592.1	0.00	0.01	0.04	0.17	0.67	6.76	33.7	88.5	232.4	1157.3	11709.1	3258.0
WacoL	25.20	45.0	0.00	0.00	0.00	0.00	0.00	0.04	0.2	0.6	1.8	9.4	104.4	182.0
WacoG	846.41	1092.0	0.00	0.23	0.53	1.79	5.29	32.34	113.5	241.5	514.1	1804.2	11022.0	6530.1
High	1211.95	1324.2	133.76	70.47	92.90	140.62	203.24	376.11	576.4	745.2	963.5	1476.7	2732.6	7398.1
Belton	78.45	211.4	0.00	0.00	0.00	0.00	0.00	0.02	0.1	0.4	1.1	7.3	109.3	1207.7
George	22.78	32.9	0.00	0.00	0.00	0.01	0.04	0.27	1.1	2.4	5.5	21.8	157.7	151.3
Grang	94.61	137.4	0.00	0.00	0.00	0.02	0.06	0.63	3.1	8.1	21.2	104.5	1039.7	672.9
Camer	633.92	863.7	0.00	1.42	2.56	6.17	13.51	50.01	124.0	214.1	369.8	916.8	3394.3	4769.5
Bryan	2848.98	2958.4	0.00	16.33	27.61	60.72	122.31	394.06	887.3	1445.8	2356.0	5304.7	17091.2	13781.9
Hemp	4011.41	3551.8	200.88	280.01	365.64	545.59	778.58	1410.44	2130.0	2729.4	3497.6	5281.9	9568.4	17535.0

The main purpose of the DATA record is to create a data array that is stored in computer memory to be accessed by any number of frequency and time series records that follow in the TIN file. However, the array can also be written in the TOU file. The first table in the TOU output file of Table 7.29 is an optional tabulation of the annual data series array activated by option 1 entered in column 52 of the DATA record.

The quantities in the tables of Table 7.29 are the minimum naturalized flow volume in any seven consecutive days of a year at the eleven control points in units of acre-feet. Any other alternative units such as acre-feet/day or cubic feet per second could be easily adopted by changing input parameters on the DATA record.

The three frequency tables in Table 7.29 were created with the 6FRE records in Table 7.28 using the eleven 58-year annual series created with the DATA record and recorded as the first table in Table 7.29. The 6FRE record routines read these data from arrays in computer memory. Only one 6FRE record is necessary. However, the three 6FRE records are included in this example to illustrate alternative frequency analysis options.

The two frequency tables on the preceding page were created with the first two 6FRE records in the TIN file. The computations are the same but the results are organized differently. Options 1 and 2 in column 20 of the 6FRE record specify row and column formats, respectively. The row format is more compact, but the column format allows larger amounts and more digits to right of the decimal and more provides more frequencies.

Parameter METHOD in 6FRE record field 6 provides three options for performing frequency analyses which are described in the *Reference Manual*: (1) relative frequency, (2) log-normal probability distribution, and (3) normal distribution. The two frequency tables on the preceding page are based on relative frequency. The third (last) frequency table in Table 7.28 is based on the log-normal probability distribution. The two alternative computational methodologies yield significantly different results. Flow frequency metrics at four of the control points computed based on relative frequency versus the log-normal probability distribution are compared in Table 7.30. The selection between the two alterative frequency analysis approaches depends on further exploration of whether the log-normal probability function accurately models the random variable being considered, in the case the minimum annual 7-day flow volume. The results based on relative frequency are adopted for application later in Example 7.4.

Table 7.30
Comparison of Results based on Relative Frequency versus Log-Normal Probability

Control Point	Exceedance Frequency	Relative Frequency	Log-Normal Probability
		(acre-feet)	(acre-feet)
Cameron Gage	90%	31.74	13.51
(Camer)	50%	326.3	214.1
	10%	2,011	3,394
Highbanks Gage	90%	182.3	203.2
(High)	50%	801.0	745.2
	10%	2,866	2,733
Bryan Gage	90%	349.6	122.3
(Bryan)	50%	1,958	1,446
	10%	7,015	17,091
Hempstead Gage	90%	804.6	778.6
(Hemp)	50%	3,259	2,729
	10%	9,052	9,568

The frequency tables in Table 7.29 contain the mean, standard deviation, and maximum of the 58 minimum annual 7-day naturalized flow volumes in acre-feet. The maximum flow volume tabulated in the last row or column of the three 6FRE frequency tables is the largest of the 58 amounts listed in the first table of Table 7.29 which is created by the DATA record. The minimum 7-day flow volumes exceeded during specified percentages of the 58 years are tabulated based on relative frequency counting in the first two frequency tables. The quantities associated with the specified exceedance frequencies are computed based on applying the Gaussian normal probability function to the logarithms of the flow volumes in the last table.

The quantities tabulated in Table 7.31 are used in defining environmental instream flow requirements as discussed in the next section. These quantities are from the first frequency table of Table 7.29 and are interpreted as follows. The minimum 7-day naturalized flow volume at control point Camer exceeds 326.27 acre-feet during 29 of the 58 years of the 1940-1997 hydrologic period-of-analysis. Thus, the 50% exceedance frequency (median) annual minimum 7-day flow volume is 326.27 acre-feet. The probability or chance of the minimum 7-day flow during any year exceeding 326.27 ac-ft is 0.50. A total flow volume of 326.27 acre-feet during seven days is equivalent to a mean daily flow of 46.61 ac-ft/day or 23.5 cubic feet/second (cfs).

Table 7.31
Annual Minimum 7-Day Naturalized Flows

Control Point	Exceedance Frequency	Annual Minimum 7-Day Flow Volume acre-feet	ac-ft/day	ac-ft/year	cfs
Camer	90%	31.74	4.53	1,656	2.3
	50%	326.3	46.61	17,024	23.5
High	90%	182.3	26.04	9,510	13.1
	50%	801.0	114.4	41,796	57.7
Bryan	90%	349.6	49.95	18,243	25.2
	50%	1,958	279.7	102,157	141.0
Hemp	90%	804.6	115.0	41,985	58.0
	50%	3,259	465.6	170,071	234.8

Example 7.5 Building Targets for Instream Flow Requirements

SIM/SIMD and *TABLES* features for modeling instream flow requirements are covered in the *Reference* and *Users Manuals*. The *SIM/SIMD* instream flow *IF* record and auxiliary input records representing instream flow rights are applicable with either daily or monthly simulations. However, a daily computational time step is typically more realistic than a monthly time step in modeling environmental instream flow needs and issues which are especially sensitive to short term to instantaneous flow rates.

Example 7.5 illustrates several of the many features for building instream flow *IF* record targets in a *SIMD* or *SIM* simulation along with application of *TABLES* to organize and analyze simulation results. The original monthly *Fundamentals Manual* example as well as the preceding daily Examples 7.1 and 7.2 include two simple instream flow *IF* record water rights at the Camer and Hemp control points. These two simple *IF* record rights remain in Example 7.5. Example 7.5 includes 12 additional *IF* record rights at the Camer, High, Bryan, and Hemp control points and employing more complex capabilities for building instream flow targets.

Example 7.5 illustrates features and options that are available for building *IF* record targets to support modeling of environmental instream flow. Low to high flow requirements can be modeled with the features and options applied in Example 7.5. Individual high flow events, known as high flow pulses, are the focus of Chapter 8. The pulse flow *PF* record and pulse flow options *PO* record are introduced in Chapter 8 and facilitate tracking of pulse flow events and setting instream flow targets based on regulated flows during the event. Use of the *PF* and *PO* records is illustrated with an example in Chapter 8 that models a hypothetical environmental flow regime covering the low to high flow spectrum of environmental instream flow requirements. The *PF* and *PO* records are specific to *SIMD* and sub-monthly time step simulations where the flow variability within individual rainfall-runoff events can be represented with a daily flow pattern. The purpose of Example 7.5 is to illustrate the features and options that are available in both *SIM* and *SIMD* for modeling environmental instream flow requirements other than those requirements related to protecting high flow pulse events.

A comprehensive flexible array of options are available in *SIM/SIMD* for modeling instream flow requirements as *IF* record water right targets using various combinations of the various options provided by *IF* records and auxiliary *TO*, *SO*, *TS*, *WS*, *BU*, *PX*, *DI*, *IP*, *IS*, *IM*, *CV*, and *FS* records as described in Chapter 3 of the *Reference Manual* and Chapter 3 of the *Users Manual* along with *DW* and *DO* records described in Appendix A of this *Daily Manual*. However, Example 7.5 focuses on applying only certain features of the cumulative volume *CV*, flow switch *FS*, daily options *DO*, and drought index *DI*, *IS*, *IP*, and *IM* records along with the *IF* records to specify instream flow requirements in a *SIMD* DAT file.

The minimum regulated flow targets set by the twelve new instream flow rights in Example 7.5 are based on the naturalized flow quantities tabulated in Table 7.31 of Example 7.4 along with the additional information provided in Tables 7.32 and 7.33. The additional *SIM/SIMD* input records inserted in Example 7.5 in the DAT file reproduced as Table 7.20 of Example 7.2 are presented in Table 7.34. The set of instream flow requirements is modeled by the 14 *IF* records and supporting records presented in Table 7.34.

Table 7.32
Once-Per-Year High Flow Target Ranges

Control Point	Minimum Daily Target	Minimum Annual Target	Upper Limit
	(ac-ft/day)	(ac-ft/year)	(ac-ft/day)
Camer	9,000	3,287,330	36,000
High	15,000	5,478,880	80,000
Bryan	25,000	9,131,470	100,000
Hemp	25,000	9,131,470	100,000

Table 7.33
Reservoir Storage Capacity Used to Define Drought Indices

Index 1 Reservoirs	Conservation Capacity	Total Capacity
	(acre-feet)	(acre-feet)
Belton	457,600	1,091,320
Georgetown	37,100	130,800
Granger	65,500	244,200
Total	560,200	1,466,320
40%	224,080	

Index 2 Reservoirs	Conservation Capacity	Total Capacity
	(acre-feet)	(acre-feet)
PK	570,240	665,540
Whitney	627,100	2,000,000
Waco	192,100	726,400
Total	1,389,440	3,391,940
40%	555,776	

Table 7.34
Records Inserted in DAT File to Model Instream Flow Requirements

```
UC UCIF3       0       0       0       0       0      30
              31      31      30      31       0       0
**-----!-------!-------!-------!-------!-------!-------!-------!-------!
**
IF Camer   3600.   NDAYS       0                   IF-1
IF  Hemp 120000.   NDAYS       0                   IF-2
**
**
WR Camer       1               0   8                           1 DI-1
DW         1
DO            18
IF Camer   7131.   UCIF3       0   2           1  IF-3
CV     1            -1.0   326.3                       4   6           3
FS    10             0.0     1.0     0.0     0.9   1           0           1    DI-1
DO                19
IF Camer                       0   2              IF-4
CV     1            -1.0   31.74                           6           3
DO                19
IF Camer 3287330   NDAYS       0   2           1  IF-5
FS     1             0.0     1.0   9000.  36000.   2       1 365           3
DO                19
**
**
WR  High       1               0   8                           2 DI-2
DW         1
DO            18
IF  High                       0   2              IF-6
CV     1            -1.0   801.0                           6           3
FS    10             0.0     1.0     0.0     0.9   1           0           1    DI-2
DO                19
IF  High                       0   2              IF-7
CV     1            -1.0   182.3                           6           3
DO                19
IF  High 5478880   NDAYS       0   2           2  IF-8
FS     1             0.0     1.0  15000.  80000.   2       1 365           3
DO                19
**
**
IF Bryan                       0   2              IF-9
CV     1            -1.0   1958.                           6           3
FS    10             0.0     1.0     0.0     0.9   1           0           1    DI-2
DO                19
IF Bryan                       0   2              IF-10
CV     1            -1.0   349.6                           6           3
DO                19
IF Bryan 9131470   NDAYS       0   2              IF-11          Hemp
FS     1             1.0     0.0  25000. 100000.   1           0           1
FS     1             1.0     0.0          25000.   2 365     365           3
DO                19
**
**
IF  Hemp                       0   2              IF-12
CV     1            -1.0   3259.                           6           3
FS    10             0.0     1.0     0.0     0.9   1           0           1    DI-2
DO                19
```

Table 7.34 Continued
Records Inserted in DAT File to Model Instream Flow Requirements

```
IF  Hemp                    0   2              IF-13
CV    1           -1.0   804.6                          6           3
DO                19
WR  Hemp                    0   8                             2 REG-HEMP
TO   -2
DO        16
IF  Hemp  293902   NDAYS       0   2              IF-14
FS    10           0.0     1.0     1.0   1.333   3           1           3    REG-HEMP
FS    10           0.0     1.0     0.0     0.9   1           0           1    DI-2
DO                19
**
DI     1       3  Belton  George   Grang
IS     4     0.0 224080. 224080. 1466320
IP           0.0     0.0   100.0   100.0
IM     1   2   3   4   5  -5  -5  -5  -5  -5  11  12
**
DI     2       3      PK    Whit   WacoL
IS     4     0.0 555776. 555776. 3391940
IP           0.0     0.0   100.0   100.0
ED
```

The instream flow requirements are defined by the set of *IF* records and supporting flow switch *FS*, use coefficient *UC*, cumulative volume *CV*, daily options *DO*, and drought index *DI*, *IS*, *IP*, and *IM* records reproduced in Table 7.34 and inserted in the DAT file of Table 7.20. *UC* records are grouped together. The set of *IF* and *FS* records are placed in the water rights section. The set of *DI*, *IS*, *IP*, and *IM* records are inserted at the end of the DAT file.

All of the record types in Table 7.34, except the *DO* record, are applicable in either *SIM* monthly or *SIMD* daily simulations and are described in the *Reference* and *Users Manuals*. The daily options *DO* record is explained in Appendix A of this *Daily Manual*. The *DO* records are inserted in the DAT file of this example to activate the *CV* and *FS* target setting specifications on a daily rather than monthly basis. Thus, the *CV* and *FS* specifications are applied in setting targets each day.

Water rights IF-1 and IF-2 remain unchanged in Example 7.5. Twelve other *IF* record rights are added. The instream flow requirements added in Example 7.5 are minimum regulated flow targets at control points Camer, High, Bryan, and Hemp that vary with specified conditions.

The instream flow *IF* record rights are senior to all of the *WR* record water rights in the dataset. The *WR* record rights curtail stream flow depletions (storage refilling and diversions) as necessary to prevent regulated flows from falling below the targets set by the *IF* records. With the default *IFMETH* option 1 selected in field 8 (blank columns 39-40) of all of the *IF* records, releases from reservoir storage are not made to meet instream flow targets in Example 7.5.

Multiple *IF* record minimum regulated flow targets are defined for each of the four control points. The entry in *IF* record column 36 selects between three options for combining targets at the same control point: (1) junior replaces senior, (2) largest controls, and (3) smallest controls. Option 2 is adopted for all *IF* record rights in Example 7.5. In each day, at a particular control point, the maximum of the flow targets set by multiple *IF* record water rights is adopted.

IF Record Rights in the Fundamentals Manual Example

The original monthly example in the *Fundamentals Manual* and the daily Examples 7.1, 7.2, and 7.5 include the first two *IF* record water rights in Table 7.34 which are labeled with the water right identifiers IF-1 and IF-2. *IF* record rights are referenced by the water right identifiers in columns 49-64 of their *IF* records. *IF* record rights IF-1 and IF-2 are minimum regulated flow targets at control points Camer and Hemp that are senior to all of the *WR* record water rights in the dataset. The *WR* record rights in the model curtail stream flow depletions (refilling reservoir storage and water supply diversions) if and as necessary to prevent flows, to the extent possible, from falling below the minimum instream flow targets set by water rights IF-1 and IF-2.

In a monthly simulation, the IF-1 and IF-2 annual target amounts of 3,600 acre-feet/year and 120,000 acre-feet/year are distributed uniformly over the 12 months of the year in proportion to the number of days in each month. Likewise, in the daily simulations of Examples 7.1 and 7.2, the annual target amounts of 3,600 and 120,000 acre-feet/year are distributed uniformly over the 365 days of each of the 43 years that have 28 days in February. The daily minimum instream flow targets are 9.8630 acre-feet/day at control point Camer for water right IF-1 and 328.767 acre-feet/day at control point Hemp for water right IF-2, with the following exception. In the 15 leap years, the IF-1 and IF-2 daily targets during the 29 days of February change to 9.5229 and 317.430 acre-feet/day, which maintains the same monthly targets in February during all 58 years.

Twelve Additional IF Record Instream Flow Rights Added in Example 7.5

Two sets of minimum regulated flow targets at four control points are established by the 12 water rights added in Example 7.5. The instream flow targets are defined based on the quantities provided in Tables 7.31, 7.32, and 7.33 and the following concepts.

- The first set of targets is designed to maintain regulated flows above levels that are representative of the 50% and 90% exceedance frequency 7-day naturalized flow volumes tabulated in Table 7.31. (IF-3, IF-4, IF-6, IF-7, IF-9, IF-10, IF-12, IF-13)
- The second set of targets at the four control points is designed to facilitate the occurrence of specified higher daily flow levels with daily flow volume falling within the range presented in Table 7.32 at least once a year. (IF-5, IF-8, IF-11, IF-14)
- The instream flow requirements vary between drought conditions and normal conditions. Drought conditions are defined for purposes of this modeling example as the total storage contents of upstream reservoirs falling below 40 percent of the total conservation storage capacity of the reservoirs. Normal conditions are defined as storage being at or above 40 percent of reservoir conservation storage capacity.

The storage contents of the reservoirs located upstream of a control point are used in defining drought conditions for purposes of setting instream flow requirements at that particular control point. Drought index *DI*, *IS*, *IP*, and *IM* records developed based on the reservoir storage capacities listed in Table 7.33 simulate this target triggering mechanism.

Priorities of zero in column 32 of all the *IF* records make them senior to all of the *WR* record water rights. The *IF* records are grouped together in the DAT file. With option 2 in *IF* record field 7 selecting the largest of multiple targets at the same control point, the sequential order of placement of the *IF* records in the DAT file does not affect simulation results.

<u>*WR Record Water Rights DI-1 and DI-2*</u>

The target building process in a *SIMD* daily simulation contains 22 steps. The steps are described in Chapter 3. Drought index factors are multiplied against beginning-of-month targets in steps 3 and 6. The beginning-of-month target is distributed to daily amounts throughout the month at step 13 using a uniform distribution or an optional *ND* number of days distribution. Drought index factors may be applied at step 18 of the target building process with the use of *DO* record field 4. Applying drought index factors at step 18 will affect the daily target, but will not affect a target developed at the beginning of the month. The target developed at the beginning of the month will continue to be distributed into daily amounts at step 13. The drought index listed in *WR* record field 11 or *IF* record field 10 can only be applied once in the target building process at either step 3, 6, or 18.

FS and *CV* records are considered at step 19 of the target building process. A target built by a *CV* record on a daily basis at step 19 will not be adjusted by the daily drought index factors considered at step 18. However, a *CV* record can be adjusted by multiplication factors developed by a subsequent *FS* record at step 19. A *FS* record using field 3 option 10 can track the target developed by another water right to set multiplication factors for adjusting the daily target set by a preceding *CV* record at the same water right.

Water rights DI-1 and DI-2 are type 8 water rights that set daily diversion targets equal to exactly 1.0 when drought index 1 and 2, respectively, have set daily factors of 1.0 (100 percent) in step 18 of the target building process. Water rights DI-1 and DI-2 set daily diversion targets equal to 0.0 when their respective drought indices set daily factors of 0.0 (zero percent). A *FS* record using field 3 option 10 tracks the daily target set by either water right DI-1 or DI-2 and applies *FS* record multiplication factors of 0.0 or 1.0 from *FS* record fields 5 and 6, respectively. Configuration of a *FS* record that tracks the daily target of a separate type 8 water right with a drought index considered in step 18 allows the drought index factors to be translated to step 19.

IF record water rights IF-3, IF-6, IF- 9, IF-12, IF-13, and IF-14 are paired with a *FS* record that tracks targets set by water rights DI-1 or DI-2. The *FS* records set multiplication factors of 0.0 or 1.0, as described above, at step 19 of the target building process to adjust the daily target set by the preceding *CV* record.

<u>*IF Record Water Rights IF-3, IF-4, and IF-5 at Control Point Camer*</u>

In each day of the simulation, the final instream flow target adopted at Camer is the largest of five targets computed by water rights IF-1, IF-3, IF-4, and IF-5. Rights IF-1, IF-4, and IF-5 each compute one target, and IF-3 computes two targets. The largest is applied.

IF-3 and IF-5 are the only instream flow rights in this example that vary seasonally. The IF-3 target is non-zero for only the five months June through October as defined by the *UC* record labeled UCIF3. IF-3 and IF-5 are both connected to drought index 1 which has a monthly varying storage trigger defined by an *IM* record. The storage contents at the beginning of May define a single constant target multiplier factor applied during May, June, July, August, September, and October. For IF-5, the storage contents at the beginning of the months of November through April set the target multiplier factor for each of the individual months.

Drought index 1 is based on whether the total storage contents in Belton, Georgetown, and Granger Reservoirs exceed 224,080 acre-feet, which is 40 percent of their total conservation storage capacity. During May, June, July, August, September, and October, the storage targets computed by IF-3 and IF-5 are multiplied by 1.0 (100 percent) if the storage capacity in the three reservoirs at the beginning of May exceeds 224,080 acre-feet and otherwise multiplied by 0.0 (zero percent). For the other months, the target is multiplied by 1.0 or 0.0 depending on whether the storage contents of the three reservoirs at the beginning of each particular month exceeds 224,080 acre-feet.

Drought versus normal conditions are defined by *DI/IS/IP/IM* records based on reservoir storage contents. IF-1 discussed on the preceding page is not connected to a drought index and is in effect continuously. IF-3 and IF-5 are connected to drought index 1 by the 1 in *IF* record column 48. IF-3 and IF-5 are activated only during normal conditions, not during drought conditions as defined by drought index 1. The much smaller IF-4 target replaces the IF-3 target during drought conditions.

IF-3 computes two quantities each day and selects the largest. A target of 46.61 ac-ft/day activated only during June through October (months 6, 7, 8, 9, 10) is computed by *SIMD* by combining an annual amount of 7,131 ac-ft/year (46.61 ac-ft/day for 153 days) with the *UC* record labeled UCIF3. The second IF-3 target maintains a 7-day moving total of 326.3 acre-feet

- during June through October if the storage contents of the three upstream reservoirs is at least 40 percent of capacity at the beginning of May and
- during the other 7 months of the year as long as the reservoir storage contents at the beginning of each individual month is at least 40 percent of capacity.

IF-3 uses drought index 1 in step 3 of the target building process to adjust target developed at the beginning of each month from *IF* record field 3. Drought index 1 must also applied a second time on a daily basis to adjust the target developed by the *CV* record in step 19 of the target building process. A *FS* record follows the *CV* record in order to apply multiplication factors to the final daily target computed by the *CV* record. The *FS* record tracks the daily target set by water right DI-1. Water right DI-1 sets a daily target of 0.0 or 1.0 according to the daily state of drought index 1.

IF-4 maintains a 7-day moving total of 31.74 acre-feet (Table 7.31) throughout the year. The daily target during June through October developed by IF-3 based on the 7-day flow volume of 326.3 acre-feet will be greater than the target set by IF-4 based on the 7-day flow volume of 31.74 acre-feet. However, IF-4 is relevant during the other six months of the year.

Water right IF-5 is based on facilitating an occasional day of higher flows. A desirable flow range is specified in Table 7.32 for each of the four control points. The instream flow requirements include maintaining a flow in this range for at least one day in any period of 365 days. This objective can also be stated as maintaining an interval of no more than 365 days between occurrences of flows falling in the specified range. IF-5 sets a daily target of 9,000 acre-feet/day any time. Since IF-5 is connected to drought index 1, the target is activated only during non-drought conditions when the volume of water stored in the three upstream reservoirs is at least 40 percent of capacity.

The IF-5 daily target of 9,000 ac-ft/day is set on the *IF* record as an annual target evenly distributed over the average of 365.259 days of the 15 leap years and 43 other years as follows.

```
IF Camer 3287330   NDAYS       0   2           1  IF-5
```

annual target = 9,000 ac-ft/day for 365.259 days = 3,287,330 ac-ft/year

The 3,287,330 ac-ft/year target is applied to all years with the daily target during February varying a little between leap years with 366 days versus regular years with 365 days. The annual target is constant, but daily targets vary slightly during February in leap years (29 days) versus non-leap years (28 days). The targets for the other 11 months do not vary between leap years and other years.

As an alternative, the *IF* record for IF-5 could be replaced with the following *IF* and *DW* records.

```
IF Camer   9000.               0   2           1  IF-5
DW         1
```

With the XDAY option activated on a *DW* record, the 9,000 acre-feet/day is treated the same in all days of either 365 or 366-day years. Thus, the equivalent annual target for the fixed daily target of 9,000 ac-ft/day larger would be larger for a year with 366 days than a 365-day year.

A third alternative for setting the target of IF-5 is to utilize the pulse flow *PF* and pulse option *PO* records in combination with the *IF* record for this water right. A *PF* record with a trigger flow of 9,000 ac-ft, event duration of 1 day, and a tracking window of 365 days could be used along with any optional features on the *PO* record. The *PF* and *PO* records are discussed further in Chapter 8 and Appendix A.

IF Record Water Rights IF-6, IF-7, and IF-8 at Control Point High

Minimum regulated flow targets for rights IF-6 and IF-7 are based on the 7-day naturalized flow volumes of 801.0 and 182.3 acre-feet from Table 7.31. Under normal conditions as defined by drought index 2, the target developed by IF-6 is larger than the IF-7 target and thus controls. The smaller IF-7 requirement replaces IF-6 during drought conditions. Drought index 2 is applied to IF-6 through *FS* record tracking of the daily target set by DR-2.

During each current day of the simulation, the *CV* records of IF-6 and IF-7 check the cumulative regulated flow volume over the preceding six days to determine whether the seven day targets of 801.0 and 182.3 acre-feet have already been satisfied. The current day target is set by subtracting the total flow during the preceding 6 days from the total 7-day target.

IF-8 is designed to maintain a daily flow within the range between 15,000 ac-ft/day and 80,000 ac-ft/day specified in Table 7.32 for at least one day during any period of 365 days, if possible. The *FS* record maintains a count of the number of times that the daily regulated flow was within this range during the preceding 365 days. The instream flow right IF-8 target is not activated as long as the last occurrence that the daily regulated flow at control point High fell within the range of 15,000 to 80,000 ac-ft/day was within the preceding 365 days. Otherwise, the minimum limit on regulated flow is targeted at 15,000 ac-ft-day to preserve such high flows if they do occur. *IF* record rights do not guarantee that regulated flows meet or exceed targets. They simply cause junior rights to curtail depletions to protect flows to the extent possible. Additionally, regulated flows measured at the priority of the *IF* record right may be significantly different than the regulated flow measured at the end of the time step.

IF Record Water Rights IF-9, IF-10, and IF-11 at Control Point Bryan

IF-9 and IF-10 are based on the 7-day flows tabulated in Table 7.30. The larger target developed by IF-9 is applicable during normal conditions. IF-10 replaces IF-9 during drought conditions. IF-9 and IF-10 at control point Bryan are similar to IF-6 and IF-7 at control point High but with different amounts.

IF-11 is designed to maintain a daily flow within the range specified in Table 7.32 for at least one day during any period of 365 days, if possible. The intent of IF-11 is the same as IF-5 and IF-8. However, IF-11 uses a different approach to selecting the day in which to apply a one-day *IF* record target of 25,000 ac-ft. The first *FS* record of IF-11 sets a multiplication factor of 1.0 any day that the regulated flow is between 25,000 and 100,000 ac-ft at water right priority zero. No preceding days are considered by the first *FS* record. The second *FS* record sets a multiplication factor of 1.0 any day in which the end-of-day regulated flow in all 365 preceding days was less than 25,000 ac-ft. The second *FS* record is used by IF-11 to identify periods of reduced stream flow in lieu of using a drought index. Therefore, IF-11 will only activate a daily *IF* record target of 25,000 ac-ft when the regulated flow at priority zero is between 25,000 and 100,000 ac-ft and the preceding 365 days have all recorded end-of-day regulated flow below 25,000 ac-ft. In all other days, the daily target of IF-11 is set to zero according to field 6 of both *FS* records.

IF-11 is the only right in this example that activates the option of applying a target at multiple control points defining a stream reach. The control point identifier Hemp is entered for the parameter *CP2* in *IF* record field 12. The minimum regulated flow target set by IF-11 is applied at both control points Bryan and Hemp.

IF Record Water Rights IF-12, IF-13, and IF-14 at Control Point Hemp

The target at Bryan set by IF-11 is also applied at Hemp as discussed in the preceding paragraph. The objective of IF-11 is to have a recurrence interval of no greater than 365 days between occurrences of daily flows within the range of 25,000 ac-ft/day to 100,000 ac-ft/day at both control points Bryan and Hemp which implies the entire reach between them. Any number of control points in the same reach can be assigned the same target by a single *IF* record right.

IF-12 and IF-13 are based on the 7-day stream flows at control point Hemp tabulated in Table 7.30. IF-12 governs during non-drought conditions as defined by drought index 2 and the target set by IF-13 controls during drought conditions. IF-14 is only activated during non-drought conditions.

IF-14 is the only right in this example to activate the *FS* record option of considering whether flows are increasing or decreasing during preceding days in setting the target for the current day. Option 3 activated by *FS* record field 9 compares the flow summation during the preceding day to flow summation in the current day. The previous and current flow summations are multiplied by field 7 and 8 factors, respectively. If the adjusted summation of the previous day is less than the adjusted summation of the current day, then the target is multiplied by the field 5 factor. Otherwise, the target is multiplied by the field 6 factor.

The *FS* field 7 and 8 factors are set to 1.0 ad 1.333, respectively. When applied to the previous and current flow summation, these factors will require the flow summation to decrease by 75 percent in order to apply the field 6 factor of 1.0 to the target of IF-14. If the flow summation increases from the previous to the current day, or if the flow summation decreases but the decrease is not greater than 75 percent, then the field 5 factor of 0.0 is applied to the target of IF-14.

Water right REG-HEMP is a type 8 right that sets a daily target equal to the end-of-day regulated flow from the previous day. The target set by REG-HEMP is used as the flow summation variable for the first *FS* record of right IF-14. The *FS* record field 9 option 3 compares the flow summation of the previous and current day. By using the target set by REG-HEMP, the FS record compares the regulated flow two days before the current day to the regulated flow one day before the current day. For example, if the current day is Wednesday, the FS record computation is based on whether the daily regulated flow volume during Tuesday was more or less than 75 percent of the daily flow volume on Monday.

The annual target of 293,902 acre-feet/year on the *IF* record for IF-14 translates to a daily target of 804.6 ac/ft/day which is the entire 7-day total from Table 7.31. Right IF-14 sets the daily target at the total 7-day flow at the 90% exceedance level if the regulated flow rate decreases by more than 25 percent between the preceding two days.

In each day of the simulation, the final instream flow target adopted at Hemp is the largest of five targets computed by water rights IF-2, IF-11, IF-12, IF-13, and IF-14. The entry in *IF* record column 36 selects between three options for combining targets at the same control point: (1) junior right replaces senior right, (2) largest target controls, and (3) smallest target controls. Option 2 is adopted for all *IF* record rights that are added to the DAT file in Example 7.5. In each day, at a particular control point, the maximum of the flow targets set by multiple *IF* record water rights is adopted.

Tables 7.35 and 7.36 compare flow-frequency metrics developed from Examples 7.2 and 7.5. The DAT file from Example 7.2 is the same as Example 7.5 except for the additional twelve *IF* record rights added at control points Camer, High, Bryan, and Hemp. Table 7.35 compares daily regulated flow frequency tables and Table 7.36 compares daily unappropriated flow frequency tables. As expected, daily mean regulated flow-frequency increases throughout the basin with the addition of the twelve instream flow requirements in Example 7.5. Mean daily unappropriated flow-frequency increases slightly at the Bryan and Hemp control points with the addition of the twelve instream flow requirements. This is a result of additional flow being passed from control points upstream of Bryan and Hemp in order to meet the additional requirements at the Camer and High control points. Mean daily unappropriated flow decreases considerably at all control points upstream of Bryan and Hemp.

Table 7.35
Regulated Flow Frequency Tables Based on Daily Flow Volumes

EXAMPLE 7.2 FLOW-FREQUENCY FOR REGULATED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	1450.09	5397.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	1815.4	3478.3	225053.7
Whit	2445.13	7305.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	318.8	1059.6	2217.0	3953.9	287270.2
WacoL	717.59	2332.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	26.6	471.3	2127.1	39700.0
WacoG	4295.37	9788.4	0.00	0.00	0.00	0.00	109.42	880.20	1402.2	1880.5	2367.5	3326.0	8196.1	363426.5
High	5291.08	11776.4	0.00	0.00	0.00	0.00	262.88	1080.73	1698.6	2152.4	2690.4	3898.6	10932.9	393203.2
Belton	927.91	2692.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	73.5	393.0	2642.4	45038.3
George	98.93	549.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	2.6	190.8	7930.0
Grang	377.14	1315.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	17.6	209.2	907.1	22946.6
Camer	2788.03	6650.4	0.00	1.56	9.52	9.86	9.86	125.54	450.5	790.2	1252.7	2343.0	6816.7	205683.6
Bryan	9084.48	18081.5	0.00	0.00	49.24	244.49	931.74	1968.19	2776.6	3347.2	4220.0	7585.5	22336.0	751659.5
Hemp	10055.91	22374.9	0.00	0.00	0.00	62.56	252.60	328.77	328.8	687.5	2728.3	9421.0	29783.3	446549.9

EXAMPLE 7.5 FLOW-FREQUENCY FOR REGULATED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	1463.33	5408.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	1825.2	3478.3	226417.7
Whit	2679.83	6928.3	0.00	0.00	0.00	0.00	0.00	114.50	553.7	1045.7	1624.3	2714.7	4632.3	210114.2
WacoL	776.83	1914.8	0.00	0.00	0.00	0.00	0.00	6.18	82.6	164.0	310.2	765.0	2126.6	39700.0
WacoG	4404.76	9171.6	0.00	0.00	0.00	0.00	128.31	1065.63	1674.4	2147.9	2717.6	3693.8	8965.2	208223.1
High	5461.29	11095.6	0.00	0.00	0.00	37.45	308.29	1315.35	2017.0	2517.0	3136.2	4596.4	11721.4	212063.8
Belton	956.74	2372.3	0.00	0.00	0.00	0.00	0.00	0.00	14.9	223.5	336.5	760.6	2469.4	19800.0
George	105.15	433.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	2.8	12.2	53.4	274.9	7930.0
Grang	389.05	1128.6	0.00	0.00	0.00	0.00	0.00	0.00	8.5	61.3	132.5	332.2	992.6	20547.2
Camer	2938.15	6528.7	0.00	3.54	9.86	9.86	9.86	211.50	594.7	924.8	1456.9	2918.0	7711.9	210615.4
Bryan	9362.41	18297.7	0.00	0.00	0.07	182.43	852.43	2105.44	3051.1	3668.1	4802.1	8808.0	22113.4	832752.7
Hemp	10351.09	22482.7	0.00	0.00	0.00	0.00	0.00	328.47	715.6	1400.5	3483.6	10335.8	29764.5	515596.6

Table 7.35
Unappropriated Flow Frequency Tables Based on Daily Flow Volumes

EXAMPLE 7.2 FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
PK	451.61	3297.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	93238.2
Whit	958.04	4388.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1256.2	70782.6
WacoL	510.61	2044.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1418.8	39700.0
WacoG	2542.39	7827.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	269.2	1445.9	5888.6	201749.8
High	3504.07	9645.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	777.2	2433.9	8929.7	189044.5
Belton	433.13	2009.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	45038.3
George	39.56	200.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	6718.4
Grang	210.81	944.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	475.0	18660.6
Camer	2104.77	6179.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	119.6	1236.4	5857.6	205673.8
Bryan	7345.73	18181.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	1910.9	6532.4	21164.3	751659.5
Hemp	9754.80	22362.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	358.8	2401.3	9092.2	29454.5	446221.1

EXAMPLE 7.5 FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
PK	390.51	3859.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	148421.8
Whit	627.18	4479.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	117359.4
WacoL	116.07	1206.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	39700.0
WacoG	1073.16	6344.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	153404.2
High	1383.35	7295.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	741.6	197053.1
Belton	122.30	1051.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	18568.6
George	12.70	123.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	4295.2
Grang	55.61	459.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	15554.1
Camer	1074.66	4964.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	2124.2	201609.0
Bryan	7529.40	18250.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	383.3	2679.7	7563.3	20676.7	832752.7
Hemp	9982.12	22478.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	849.4	3042.9	9941.1	29397.9	515267.8

Tables 7.37, 7.38, 7.39, and 7.40 present the monthly aggregated instream flow targets set at the High, Camer, Bryan, and Hemp control points, respectively. No instream flow targets were set at the High and Bryan control points in Example 7.2. Only instream flow targets were set by rights IF-1 and IF-2 at the Camer and Hemp control points, respectively. IF-1 sets an instream flow target of 9.8630 ac-ft/day or 3,600 ac-ft/year. IF-2 sets an instream flow target of 328.767 ac-ft/day or 120,000 ac-ft/year.

IF-9, IF-10, and IF-11 set instream flow targets at control point Bryan. However, there are few months shown in Table 7.39 with instream flow targets. The primary source of the targets shown in Table 7.39 is a result of IF-11. IF-9 and IF-10 are not required to set many daily instream flow targets to satisfy the 90% and 50% exceedance 7-day flow volume at Bryan. Instream flow targets set upstream at control points High and Camer and instream flow targets set downstream at Hemp result of regulated flows that also satisfy the 7-day flows at Bryan.

Table 7.37
Monthly Aggregated Instream Flow Targets for Control Point High, ac-ft

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	1342	0	0	0	375266	450319	465329	465329	450319	465329	450319	465329	3588882
1941	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1942	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1943	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1944	0	0	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	4593252
1945	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1946	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1947	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	679	5014229
1948	465329	0	465329	0	0	0	330234	0	0	1352	1922	412	1264579
1949	0	0	0	0	801	450319	465329	465329	450319	465329	450319	465329	3213075
1950	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1951	465329	420298	0	0	0	0	465329	0	0	0	0	0	1350956
1952	0	0	0	0	0	0	1332	135	458	70	0	0	1996
1953	0	0	0	123	0	450319	0	465329	450319	892	450319	465329	2282630
1954	465329	420298	0	0	0	450319	465329	0	0	0	46	2557	1803879
1955	4396	55	64	0	182	450319	465329	465329	0	465329	450319	465329	2766653
1956	465329	420298	465329	450319	0	450319	0	0	0	923	0	0	2252516
1957	0	0	0	0	465329	450319	465329	465329	450319	465329	450319	465329	3677604
1958	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1959	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1960	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1961	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1962	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1963	465329	420298	465329	450319	465329	450319	465329	465329	450319	0	0	0	4097901
1964	403	182	0	0	0	0	0	0	0	0	0	0	586
1965	0	0	465329	0	0	450319	465329	465329	450319	465329	450319	465329	3677604
1966	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1967	465329	420298	465329	450319	465329	450319	465329	465329	375266	15011	450319	465329	4953507
1968	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1969	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1970	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1971	465329	420298	465329	0	0	0	0	0	450319	465329	450319	465329	3182253
1972	465329	420298	465329	450319	465329	450319	0	0	0	0	341	0	2717264
1973	0	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5013550
1974	465329	420298	465329	450319	465329	450319	465329	0	0	465329	450319	465329	4563230
1975	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1976	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1977	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1978	465329	0	0	0	0	0	0	0	450319	465329	450319	465329	2296626
1979	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1980	465329	420298	0	0	0	450319	465329	0	0	0	450319	465329	2716924
1981	234	291	0	0	0	0	465329	465329	450319	465329	450319	465329	2762481
1982	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1983	465329	420298	465329	450319	465329	450319	465329	465329	0	0	0	912	3648494
1984	3212	251	0	997	0	135	30	117	21	888	0	0	5651
1985	465329	420298	465329	450319	465329	450319	465329	465329	450319	0	450319	465329	5013550
1986	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1987	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1988	465329	420298	465329	450319	465329	315223	2529	0	0	0	0	0	2584357
1989	0	0	0	0	0	450319	465329	465329	450319	465329	450319	465329	3212274
1990	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1991	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1992	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1993	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1994	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1995	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
1996	465329	420298	465329	450319	465329	0	0	0	0	465329	450319	465329	3647582
1997	465329	420298	465329	450319	465329	450319	465329	465329	450319	465329	450319	465329	5478879
MEAN	361197	318860	353010	318348	335427	378115	382838	353013	340335	345315	364953	369133	4220545

Table 7.38
Monthly Aggregated Instream Flow Targets for Control Point Camer, ac-ft

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	750	276	306	296	306	261232	279198	279198	270192	279198	270192	279198	1920341
1941	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	279198	3287331
1942	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	279198	3287331
1943	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	296	306	2738543
1944	306	276	279198	270192	279198	270192	279198	279198	270192	279198	296	306	2207749
1945	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	279198	3287331
1946	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	296	279198	3017436
1947	306	252179	279198	270192	279198	296	306	306	296	306	296	306	1083183
1948	306	276	306	296	306	296	306	306	296	306	296	306	3600
1949	306	276	306	296	306	296	306	306	296	306	296	306	3600
1950	306	276	306	296	306	296	306	306	296	306	296	306	3600
1951	306	276	306	296	306	296	306	306	296	306	296	306	3600
1952	306	276	306	296	306	296	306	306	496	746	313	306	4258
1953	306	276	306	296	306	296	306	306	296	306	296	306	3600
1954	306	276	306	296	306	363	306	536	510	306	296	306	4112
1955	306	276	306	296	306	296	306	306	296	306	296	306	3600
1956	306	276	306	296	306	296	503	329	821	328	296	306	4367
1957	306	276	306	296	279198	270192	279198	279198	270192	279198	270192	279198	2207748
1958	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	279198	3287331
1959	279198	252179	279198	270192	306	296	306	306	296	306	270192	279198	1631971
1960	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	279198	3287331
1961	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	279198	3287331
1962	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	296	306	2738543
1963	306	276	306	296	306	296	306	306	296	306	296	306	3600
1964	306	276	306	296	306	296	306	306	296	306	296	306	3600
1965	306	276	306	270192	279198	270192	279198	279198	270192	279198	270192	279198	2477644
1966	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	306	3008439
1967	306	276	306	296	306	296	306	306	296	306	296	306	3600
1968	306	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	279198	3008439
1969	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	296	306	2738543
1970	306	252179	279198	270192	279198	270192	279198	279198	270192	279198	296	306	2459651
1971	306	276	306	296	306	296	306	306	296	306	296	306	3600
1972	306	276	306	296	306	296	306	306	296	306	296	306	3600
1973	306	276	306	296	306	296	306	306	296	306	296	306	3600
1974	306	276	306	296	306	296	306	306	296	306	296	279198	282493
1975	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	306	3008439
1976	306	276	306	296	306	270192	279198	279198	270192	279198	296	306	1380068
1977	306	276	279198	296	279198	270192	279198	279198	270192	279198	296	306	1937853
1978	306	276	306	296	306	296	306	306	296	306	296	306	3600
1979	306	276	306	296	306	270192	279198	279198	270192	279198	296	306	1380068
1980	306	276	306	296	306	270192	279198	279198	270192	279198	296	306	1380068
1981	306	276	306	296	306	296	306	306	296	306	296	306	3600
1982	306	276	306	296	306	296	306	306	296	306	296	306	3600
1983	306	276	306	296	306	296	306	306	296	306	296	306	3600
1984	306	276	306	296	412	308	306	426	460	306	296	306	4002
1985	306	276	306	296	306	296	306	306	296	306	296	306	3600
1986	306	276	279198	296	306	296	306	306	296	306	270192	279198	831281
1987	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	279198	3287331
1988	279198	252179	279198	270192	279198	296	306	306	296	306	296	306	1362075
1989	306	276	306	296	306	296	306	306	296	306	296	306	3600
1990	306	276	306	296	279198	270192	279198	279198	270192	279198	270192	279198	2207748
1991	306	252179	279198	296	279198	270192	279198	279198	270192	279198	296	306	2189756
1992	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	279198	3287331
1993	279198	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	279198	3287331
1994	306	276	306	296	306	270192	279198	279198	270192	279198	296	306	1380068
1995	306	276	279198	296	279198	270192	279198	279198	270192	279198	296	306	1937853
1996	306	276	306	296	306	296	306	306	296	306	296	306	3600
1997	306	252179	279198	270192	279198	270192	279198	279198	270192	279198	270192	279198	3008439
MEAN	82058	95825	125326	107324	130137	139744	144564	144567	139916	144568	88710	91667	1434406

Table 7.39
Monthly Aggregated Instream Flow Targets for Control Point Bryan, ac-ft

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	4662	0	0	0	0	0	0	0	0	0	0	0	4662
1941	0	0	0	0	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	0	0	0	0	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	3606	0	0	3606
1947	0	0	0	0	0	523	0	0	0	0	910	298	1730
1948	1328	0	0	0	0	0	0	0	0	458	3013	0	4799
1949	0	0	0	25018	0	0	0	0	166	0	0	0	25184
1950	0	0	0	0	0	0	0	0	0	0	0	0	0
1951	0	0	0	0	0	0	0	0	37	0	0	0	37
1952	0	0	0	0	0	0	1147	707	1509	0	0	0	3362
1953	0	0	0	0	0	0	0	0	0	152	1292	0	1444
1954	0	0	0	0	0	0	0	0	0	0	0	0	0
1955	6481	0	0	0	25018	217	0	0	0	0	0	0	31716
1956	0	0	0	0	0	0	559	3427	0	2726	19	0	6731
1957	671	70	0	0	0	0	0	0	0	0	0	0	741
1958	0	0	0	0	0	0	0	0	0	0	0	0	0
1959	0	0	0	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	1431	0	0	3906	0	0	5337
1961	0	0	0	0	0	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	816	0	0	0	0	0	0	0	816
1964	170	0	0	0	0	25018	0	1601	0	0	0	0	26788
1965	0	0	0	0	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	25018	0	0	0	0	25018
1972	0	0	0	0	0	0	0	0	0	0	1014	0	1014
1973	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	8	1859	0	0	1866
1977	0	0	0	0	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	35	335	25018	0	0	0	0	25388
1979	30386	11746	0	0	0	0	0	0	0	0	0	0	42132
1980	0	0	0	0	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	25018	0	0	0	0	0	0	25018
1982	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	1038	1038
1984	252	0	44	438	1419	10	734	4286	1068	0	0	0	8251
1985	300	0	0	0	0	0	0	0	0	0	0	0	300
1986	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	25018	0	0	0	0	0	0	0	0	0	0	25018
1990	0	0	0	0	0	0	0	0	0	0	2100	0	2100
1991	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	2473	0	0	0	0	10496	15441	0	28410
1995	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0
MEAN	763	635	1	439	513	876	73	1035	48	400	410	23	5216

Table 7.40
Monthly Aggregated Instream Flow Targets for Control Point Hemp, ac-ft

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	27012	10126	17338	16057	43807	37518	12574	32344	21492	16120	12722	12098	259206
1941	11621	9682	10668	10340	12098	12245	12574	13050	23755	14480	42961	14003	187477
1942	13527	15889	15802	10816	12098	14628	15913	28358	16268	13050	10816	18653	185818
1943	12098	19226	11621	24158	15433	28665	22873	18172	17233	16424	17010	15433	218346
1944	10192	11506	13527	14151	12574	20224	29214	23552	15394	59982	15580	10668	236564
1945	11145	10635	12098	12245	14888	13198	14956	16339	15354	14003	17152	12574	164587
1946	10192	9682	11145	15104	11621	12245	19673	64630	70743	38166	13270	10668	287139
1947	10192	9682	10192	12722	12098	16575	21180	14480	23142	36749	16880	13820	197710
1948	16873	10126	10639	9863	10192	47467	33033	21815	12280	15110	19926	10192	217516
1949	10192	9206	10192	34552	20560	12245	14480	30611	39315	13858	11292	11621	218123
1950	10668	9206	11145	11292	37605	22295	56672	24082	13675	44292	34849	38709	314491
1951	47213	24893	10192	9863	16211	20333	17806	14825	17476	10192	9863	10192	209057
1952	10192	9206	10192	9863	10192	11332	10200	12267	11611	10192	9863	10192	125299
1953	10192	9206	10192	9863	11145	12245	52642	101029	60954	31580	20040	12098	341185
1954	16900	14929	10192	11290	60979	95791	22839	20184	15194	10192	10116	10192	298798
1955	13478	9206	12307	9863	35148	41678	100887	55862	38620	79649	31942	44611	473252
1956	39039	15429	17164	24512	22768	12469	10300	11141	9863	14125	10158	10192	197160
1957	13550	17295	11536	12722	11145	13198	15433	25905	27041	13050	13198	12574	186646
1958	13050	10635	10668	11292	12098	13675	14003	24084	17028	15335	16280	16386	174535
1959	15460	9206	14956	11292	14003	23013	24722	21331	19093	14956	11292	10192	189516
1960	10192	9206	10192	11769	14956	19428	37723	23726	17010	19996	11292	12574	198063
1961	10192	10158	11145	10340	15274	22388	12574	24444	25356	16862	15104	11621	185458
1962	11145	10158	10192	13163	15433	13198	27165	18291	31097	16862	31342	18246	216292
1963	17122	15365	21396	24460	49906	40738	17207	15797	30904	10192	12926	10303	266314
1964	10438	9375	10192	9863	10192	36874	10192	14146	9963	10192	10287	10192	151904
1965	10192	9206	10668	9863	11621	11769	14113	31656	27380	35765	12722	12574	197529
1966	10192	9206	11621	12245	12574	20490	18267	22721	22537	13050	19032	18020	189955
1967	18588	17752	22106	17582	22243	18695	69083	26315	37709	24249	15104	15938	305365
1968	13050	9666	11621	9863	10668	10816	13527	18696	17010	16386	13198	11145	155645
1969	10192	9206	12574	10816	10192	12722	17338	16862	42466	25183	21310	17224	206084
1970	12098	10158	10192	9863	14003	18365	17338	17815	14628	14003	15104	16386	169953
1971	16386	16489	17020	9863	10192	20003	10192	80738	97770	54550	15104	11145	359450
1972	10668	15066	18352	21157	32426	27800	10192	20184	24138	15171	16225	10192	221572
1973	11145	16938	10192	11292	13527	10340	24108	19823	27091	10796	12245	12098	179594
1974	10192	12064	16386	20206	16158	33548	13502	10192	9863	58193	18582	10668	229554
1975	19656	13017	11145	13675	13527	12245	11621	13050	31439	17049	20423	23900	200746
1976	20501	17956	17459	12976	13050	11292	10192	21258	40970	26538	10340	10192	212724
1977	10668	9206	11621	11292	14003	16057	21219	17815	19164	16922	15104	16386	179456
1978	12574	9206	10192	9914	10704	9863	10192	50412	78818	101029	97770	101029	501703
1979	49969	19932	11145	11769	10668	10340	12574	11145	15104	17759	15580	14956	200940
1980	10192	9206	10192	9863	14956	32854	17938	10192	17521	37215	97770	45970	313868
1981	11183	9732	10661	14077	13050	37210	14003	22908	20899	14956	11769	18685	199134
1982	19205	17830	13267	9863	12574	17442	12574	70420	76759	18544	16692	16210	301381
1983	19438	11111	11145	16507	14480	15511	23468	11145	9863	20660	14064	11022	178413
1984	12886	9206	10192	9863	10192	9863	10192	10421	9949	13341	9863	12574	128540
1985	35253	14635	12098	28333	59679	42251	53546	29898	14628	11621	13675	13050	328666
1986	16541	9206	17312	17888	14003	12245	24385	60583	25203	14956	12722	10192	235236
1987	10668	9206	10192	18647	14003	12722	15759	20888	17637	17456	15826	18151	181154
1988	14911	19237	14107	14151	16910	21055	18456	10707	14505	15902	9863	10192	179996
1989	10192	35103	10192	9863	13050	11292	15909	17607	34962	25936	17284	19460	220850
1990	17816	13351	12574	13198	15433	9863	16792	41094	36256	67396	30524	19456	293753
1991	10668	10158	11621	10340	14003	22476	28018	54868	39100	18768	12722	12574	245317
1992	10192	11506	10668	10340	11145	13675	14003	20600	21835	18234	13675	12574	168445
1993	11145	13017	11621	12245	12574	11769	13527	22903	24317	13342	15413	19501	181373
1994	17569	12064	15433	17098	46004	25663	28636	22204	16332	23340	26589	11621	262553
1995	10668	13792	11145	13675	14386	20486	14915	10668	27306	16386	16514	16683	186623
1996	19038	18720	20602	22559	19193	10482	10192	11438	17004	16766	12245	10192	188430
1997	10192	10158	10192	11769	15433	13198	18471	26920	16090	17296	15104	11621	176443
MEAN	15271	12785	12593	13864	18087	20656	21570	26286	26657	23868	19074	16545	227257

CHAPTER 8
MODELING PULSE FLOW REQUIREMENTS

The ability of WRAP to simulate individual flow events is improved with the daily time step modeling capabilities in *SIMD*. Flows occurring as a direct result of a rainfall-runoff event tend to have great fluctuations in flow rates over short time spans. Daily computational time steps improve the accuracy of the simulation with regard to hydrograph representation and water management or flood control response to these events. Modeling capabilities in *SIMD* addressing flood control operations are discussed in Chapter 5. This chapter introduces modeling capabilities specific to *SIMD* that address pulse flow events in the context of environmental instream flow needs.

The concept of an environmental instream flow regime is introduced and briefly discussed in this chapter to provide context with regard to the application of the pulse flow modeling capabilities presented later in the chapter. Like all simulation capabilities in WRAP, the specific input records are generalized and may have application in any context outside of the intended use. The *PF* and *PO* input records for *SIMD* are introduced and discussed prior to the pulse flow examples provided at the end of the chapter. The discussion of the *PF* and *PO* records includes the mechanics of the computations used during the simulation. The fields, variables, and descriptions for the *PF* and *PO* input records are provided in Appendix A. This chapter concludes with two examples of modeling the various types of pulse flow events that might be included in a comprehensive environmental instream flow regime recommendation.

Environmental Instream Flow Regime

IF record instream flow requirements in *SIM/SIMD* typically involve setting a single target for regulated low flows. The typical low flow *IF* record target may vary monthly according to a pattern established with *UC* records. These *IF* record applications are generally suitable to model the majority of the historical water right permit requirements that are intended to protect minimal environmental instream flow needs. An example of single low flow requirements for instream flows includes the protection of water quality. Various methods exist for developing single low flow requirements and can include evaluation of stream flow records to determine the minimum annual mean 7-day flow rate with a 2-year recurrence frequency also known as the 7Q2. However, single low flow requirements only address a small portion of the flow variability observed in most stream gage records.

Stream gage records of locations with a meaningful percentage of upstream unregulated drainage area typically exhibit a range of flow rates and rates of change in flow over various periods of time. Poff and Ward (1989) and Richter et al. (1996) characterize the natural flow regime of a stream in terms of magnitude of flow rate, quantity, event duration, event frequency, and other numerical parameters. Throughout this chapter, the term *flow regime* will be used to refer to the complete host of flow components at a location or within a stream gage record from low to high flows. A flow regime is subdivided into *components* of the flow regime. Each component has a respective set of numerical parameters that may define flow rates, quantities, durations, and frequencies that are pertinent to the component. The term *environmental instream flow requirement* is used to refer to *SIMD* instream flow *IF* records that set targets based on the defined flow regime components at a particular location.

Four components of a flow regime (TIFP, 2005) are used for developing *SIMD* environmental instream flow requirements as presented in the simulation examples in this chapter. The four components are subsistence, base, pulse, and overbank flows. Subsistence flows are the lowest magnitude flows used to set instream flow requirements. Subsistence flow requirements are intended to be applied infrequently for the protection of water quality and provide minimally survivable habitat for aquatic species. Base flows might be referred to as normal or average flow conditions that occur between significant rainfall-runoff events. Base flows provide aquatic species with a range of suitable habitats and may also contribute to nutrient and sediment transport. High flow pulse events are a response to rainfall-runoff events. High flow pulses are characterized by short duration events of elevated to high flow rate that remain within the banks of the stream. High flow pulses provide aquatic species with longitudinal connectivity along the stream and help to maintain the physical characteristics of the stream through geomorphic processes. Overbank pulse flows are high flow events that exceed the banks of the stream. Such events provide aquatic species with lateral connectivity between the stream and flood plain and shape the riparian zone as well as the stream channel. Overbank flows are typically considered flooding events and therefore may be constrained to the extent possible by upstream flood control reservoirs and related structures.

Hydrologic analyses of stream flow records to assess environmental flow needs may include consideration for seasonality or hydrologic conditions within the basin. Seasonality may influence the characteristics of base flow or pulse flow components. For example, several months of the year during the spring season may have higher base flow or pulse flow magnitudes than the months considered to be summer or autumn. Hydrologic condition can refer to the state of soil moisture and presence or lack of drought conditions in the drainage area above a stream gage. For the purposes of developing environmental instream flow requirements, the hydrologic condition is used as an indicator used to select between differing levels of flow requirements. Raising or lowering flow requirements based on the hydrologic condition may help to balance the need to preserve flow variability over time while also allowing water availability for human consumption. If the hydrologic condition is indicative of wet conditions upstream of a stream gage, it may be appropriate to set a higher base flow requirement. Conversely, a dry hydrologic condition may indicate a natural tendency for lower base flows. A lower base flow requirement may be similarly protective of environmental needs under a low hydrologic condition.

Within the State of Texas, a series of three omnibus water bills have been signed into law since the late 1990's relating to water needs for human as well as environmental needs. In 1997, Senate Bill 1 of the 75th Legislature created a comprehensive water supply planning process. In 2001, Senate Bill 2 of the 77th Legislature, among other water related items, created the Texas Instream Flow Program (TIFP) as a jointly administered program of the Texas Commission on Environmental Quality (TCEQ), the Texas Parks and Wildlife Department (TPWD), and the Texas Water Development Board (TWDB). The purpose of the program was "to perform scientific and engineering studies to determine flow conditions necessary for supporting a sound ecological environment in the river basins of Texas" (TIFP, 2005). Most recently in 2007, Senate Bill 3 of the 80th Legislature created a process for developing recommendations to meet instream flow and bay and estuary freshwater inflow needs. The Senate Bill 3 process includes a scientific and stakeholder process which culminates in the adoption of basin specific instream and freshwater inflow *standards*.

The term *environmental flow standard* refers to rules adopted by the TCEQ that are supportive of a sound ecological environment while also accounting for public interests. The environmental flow standards are established at various locations within each basin in Texas and are comprised of the components of an environmental flow regime. The environmental instream flow requirements discussed in this chapter refer to *SIMD* instream flow *IF* records that set targets based on the defined flow regime components at a particular location. The numerical parameters that define the environmental flow regime components serve as a common connection between the environmental flow standards and the *IF* record targets that set requirements within the modeling.

***SIMD* Input Records and Methods for Flow Regime Modeling**

Four components of a flow regime are examined in the context of simulation modeling in this chapter. The four components include subsistence, base, pulse, and overbank flows. The qualitative characteristics of each are described in the previous section of this chapter and are further described in detail in Poff and Ward (1989), Richter et al. (1996), Richter et al. (1997), and TIFP (2005). Input records in the DAT file are created for the purpose of setting *IF* record targets within the simulation that reflect the numerical parameters of the flow regime components. Simulation input records in addition to the *IF* record are required to address the complexity of the flow regime components at a single stream gage location. Additional input records for modeling components of an environmental flow regime can include, but are not limited to, the following:

- Pulse flow *PF* and pulse flow option *PO* records
- Flow switch *FS* or cumulative volume *CV* records
- Target option *TO* record
- Drought index *DI/IS/IP/IM* records
- Target setting water right *WR* records (field 8, option 8)

Pulse Flow PF and Pulse Option PO records

High flow pulses are characterized by short duration events with a high flow rate and may include flooding conditions. These events are a direct response to rainfall-runoff processes. The rising limb of a typical high flow pulse hydrograph climbs sharply to a peak, after which flows recede back to base flow levels. Pulse events are usually considered to be events with duration measured in days or weeks. The unique sub-monthly parameters to be used for initiating, tracking, and terminating high flow pulse events have motivated the creation of a specific set of input records for *SIMD*. The pulse flow *PF* record and pulse flow option *PO* record are discussed in this section. Tables 8.1 and 8.2 summarize the variables with a brief description for the *PF* and *PO* records, respectively. Fields and variables of these records are described in detail in Appendix A.

A *PF* record is placed in the DAT file after a *WR* or *IF* record. The optional *PO* record is placed after a *PF* record. The computations for the *PF/PO* record pair are considered in steps 19 and 20 of the target building process as outlined in Chapter 2. Any number of *PF/PO* record pairs may be assigned to the same *WR* or *IF* record.

Table 8.1
PF Record Variables and Descriptions

PF record variable	Description	*PF* record variable	Description
PFN	Numerical identifier of *PF/PO* record pair	WINDOW	Number of previous days to count pulse events
PFV	Pulse flow variable, default regulated flow	SEASON START	Month to begin season for counting pulse events, default 1
PFCP	Alternate control point for flow variable	SEASON END	Month to end season for counting pulse events, default 12
TRIGGER	Daily flow threshold that initiates a pulse event	SEASON COUNT	Number of seasons for counting pulses, default is 1
VOLUME	Terminate pulse event after total volume observed	PFTAR	Target setting options
DURATION	Terminate pulse event after a maximum number of days	PFSMM	SMM file output options
FREQ	Number of pulse events per window or season	PFWR1	Optional water right ID for defining pulse flow variable

Table 8.2
PO Record Variables and Descriptions

PO record variable	Description	*PO* record variable	Description
REGFLOW	Methods for computing regulated flow	CHANGE	Rate of change used with UPPER for terminating a pulse event
PREVIOUS EVENT	Options for initiating new pulse event after previous	SEASON TERMINATE	Termination of pulse events at the end of seasons
DELAY	Number of days between previous and new pulse	TARGET LIMT	Limit on magnitude of *PF* record target to trigger magnitude
LARGER EVENTS	Larger pulse events block initiation of smaller pulses	EXCESS EVENTS	Options for counting excess pulse events towards frequency
PREVIOUS FLOW	Regulated flow of previous day considered for initiation	EVENT VOLUME	Exclusion of pulse events failing volume criterion from count
LOWER	Lower threshold for terminating pulse event	PFWR2	Optional water right ID for target setting feature
UPPER	Upper threshold and rate of change used together for terminating pulse event	PFWR3	Optional water right ID for pulse event termination

PF/PO Record Computations

Single flow rate requirements are easily established with a single instream flow *IF* record and associated use coefficient *UC* record to distribute the annual volume into monthly amounts. This conventional application of the *IF* record may be adequate for modeling subsistence and base flow requirements that vary by month or season. With conventional *IF* record targets, a fixed or predetermined monthly or daily amount is used for the *IF* record target. This instream flow target is known prior to the simulation and is independent of the actual daily regulated flows. In the case of subsistence or base flow modeling, switching between these components may require knowledge of a hydrologic condition variable during the simulation.

Unlike conventional *IF* record target setting that is independent of the actual regulated flows, setting targets for pulse flow events is dependent on the value of regulated flow in the current day and the sequence of regulated flows within a pulse event. The daily regulated flows must be evaluated during the simulation for initiation of the pulse event according to a daily trigger flow and for cumulative flow event volume compliance. A pulse event is the consecutive days between and including the days in which regulated flows satisfied the initiation and termination criteria. Once the pulse flow event is initiated, daily targets are set according to the *PF/PO* record computations until the termination criteria are met.

The pulse flow *PF* record methodology differs from the flow switch *FS* and cumulative volume *CV* record methodology. *FS/CV* records perform continuous summation of a flow variable over a number of time steps. The computations for pulse flow *PF* records involve consideration of only those time steps between and including the time steps of event initiation and termination. The number of time steps considered within a pulse event by the *PF* record may be as few as 1 time step and as many as the maximum duration input parameter.

The computations for the *PF/PO* record pair are considered in steps 19 and 20 of the target building process as outlined in Chapter 2. The *PF/PO* computations may result in a final target that is incorporated with targets previously set by the *WR* or *IF* record. The following terms are used in describing the *PF*/*PO* record computations:

Initiate: The decision to declare a pulse event is engaged based on regulated flow exceeding the trigger criterion and satisfaction of optional initiation criteria.

Engaged: A pulse event that has been initiated and is being tracked. An engaged pulse may set daily pulse targets.

Terminate: The decision to declare a pulse event is no longer engaged based on satisfaction of either the total event volume or maximum duration parameter or satisfaction of other optional termination criteria.

Daily Pulse Target: Targets developed during a pulse event. Daily pulse targets are less than or equal to the daily regulated flow during the pulse event as measured at the priority of the *WR* or *IF* record to which the *PF* record is attached. Daily pulse targets are not used to set a final target for the *PF* record unless the frequency criterion is still unmet.

PF Record Target: Daily pulse targets that are used to establish a daily *WR/IF* record target.

Target Setting Event: Pulse events that set a *PF* record target. The number of pulse events that are less than or equal to the frequency parameter during the tracking period will be considered target setting events.

Excess Pulse Event: Pulse events that do not set *PF* record targets. When the number of pulse events exceeds the frequency parameter, the events are tracked but otherwise do not set *PF* record targets. Excess pulse events are not tracked unless the option is selected on the *PO* record.

Seasonal Tracking: Pulse events are only initiated and considered for meeting the frequency criterion between a starting and ending month. An optional number of the previous seasons may be considered together for meeting the frequency.

Continuous Tracking: Pulse events are initiated and considered for meeting the frequency criterion over the previous number of time steps equal to parameter WINDOW on the *PF* record.

The following computations are performed for the *PF/PO* records at step 19 in the target building process as outlined in Chapter 2. If more than one *PF/PO* record pair is assigned to a *WR* or *IF* record, the computations are repeated. The computations for each *PF/PO* record pair are independent of any other *PF/PO* records assigned to the same *WR* or *IF* record.

1. The month is checked to be within the seasonal cycle if ***seasonal tracking*** is selected. The computations are performed for every time step if ***continuous tracking*** is selected.
2. The daily pulse flow variable is computed. The default is to track regulated flow at the control point and at the priority of the *WR* or *IF* record.
3. A new pulse is initiated if all of the initiation criteria are satisfied. The initiation criteria include items a and b below plus any combination of options c, d, e, and f.
   a. This *PF* record is not currently tracking a pulse flow event.
   b. The regulated flow is in excess of the trigger criterion.
   c. The number of pulse flow events during the tracking period has not exceeded the frequency criteria. This criterion is ignored if the excess pulse event option is selected.
   d. An optional number of days has occurred since the termination of the previous pulse event.
   e. A pulse flow event with a larger trigger criterion is not currently engaged at the same location according to the LARGER EVENTS option.
   f. Regulated flow for the previous day was less than the trigger criterion.
4. A pulse is terminated prior to setting a *PF* record target if the optional *PO* record termination criteria are met. These termination criteria include:
   a. A target has been set by the water right indicated by PFWR3.
   b. Regulated flow is less than the lower threshold.
   c. Regulated flow is less than the upper threshold and has decreased since the previous time step by less than the change variable.

5. If the pulse flow event is terminated by the criteria in step 4, and if the pulse event has failed to achieve to the total event volume criterion, the event is eliminated from consideration to satisfy the frequency criterion.
6. If a pulse event is engaged, the total volume of the event is updated.
7. If a pulse event is engaged, the number of pulse events engaged during the continuous tracking window or seasonal tracking period is updated for comparison with the frequency criterion.
8. The ***daily pulse target*** is computed to be equal the lesser of the following:
   a. Daily regulated flow,
   b. Remaining volume to satisfy the total event volume criterion, or
   c. Value of trigger criterion if the *PO* record target limit option is selected
9. A ***PF record target*** is set equal to the ***daily pulse target*** if all of the following criteria are met:
   a. A pulse event is currently engaged.
   b. The number of pulse events during the continuous tracking window or the seasonal tracking period is less than or equal to the frequency criterion, i.e., the current pulse event is not considered to be an ***excess pulse event***.
   c. A target has not been set in the current time step by the optional water right indicated by PFWR2 of the *PO* record.
10. The *PF* record target is incorporated as a *WR* or *IF* record target according to the options set by PFTAR on the *PF* record.
11. The pulse event is terminated after setting a *PF* record target if the total volume of the pulse event has exceeded the total event volume criterion.
12. If the pulse flow event has been engaged for the maximum duration number of days, the pulse event is terminated. If the event has failed to achieve to the total event volume criterion, the terminated event is eliminated from consideration to satisfy the frequency criterion according to *PO* record option EVENT VOLUME.
13. The pulse event is terminated if the current day is the last day of a seasonal tracking period. *PO* record option SEASON TERMINATE may allow pulse events to continue past the last day of the season until terminated by other criteria.
14. Optional daily computations are written to the SMM file.
15. If this is the last day of the last month of a seasonal tracking period, the number of excess flow events, if chosen for consideration, are computed and saved for consideration in the next seasonal tracking period. If more than one seasonal tracking period is to be considered for meeting the frequency criterion, all target setting and excess pulse events in the current season are saved for consideration in future seasonal tracking periods as set by *PF* record option SEASON COUNT.

Regulated flow computed at the priority of the *WR/PF/PO* or *IF/PF/PO* records may not be the same as the regulated flow at the end of the time step. The difference in regulated flow within the priority sequence versus regulated flow computed at the end of the time step will be influenced by upstream *WR* records that are junior to the pulse flow target setting rights. Steps11 through 14 are repeated to adjust the total event volume at the end of the time step if regulated flow is chosen as the pulse flow variable and *PO* record option REGFLOW is selected.

<u>Selecting PF/PO Record Variables</u>

The *PF* and *PO* records are generalized for modeling high flow pulses. The required and optional variables on the *PF* and *PO* records can address a wide range of initiation, termination, and target setting aspects for modeling the pulse flow components within a flow regime. Tables 8.1 and 8.2 list the variable names and provide a brief description. Additional details necessary for developing input records are provided in Appendix A. Values are assigned to the trigger, volume, duration, and frequency variables and a selection between continuous or discrete seasonal tracking periods is made on the *PF* record. Other variables on the *PF* record are optional or have default values. If a *PO* record is not provided after a *PF* record, all default values of the *PO* record variables are assumed.

Selecting continuous or seasonal tracking periods is dependent on the expected occurrence of the pulse flow component of the flow regime. If the pulse flow component is defined for a specific season or specific months, seasonal tracking should be selected on the *PF* record. If a pulse flow component is not defined for a specific season or specific months, then a continuous tracking period may be appropriate. A pulse flow with a frequency requirement of 1 event per year or 1 event per multiple years might be modeled with a window equal to 364 or more days prior to the current time step. Alternatively, such a pulse flow could be modeled with a 12 month seasonal tracking period with the option to consider a number of previous seasons.

Excess pulse flow events are most likely to be applied with continuous tracking or with seasonal tracking that includes consideration of previous seasons. Seasonal tracking periods that only consider the current seasonal period may not be suited for considering excess flow events. This may especially be true for seasonal periods defined by only a few months per year. Considering excess flow events represents a type of pulse flow memory that may not have an ecological significance if several months, seasons, or years intervene.

Excess pulse flow events do not set *PF* record targets and therefore will not result in an *IF* record protection of regulated flow. As such, excess flow events may be particularly prone to failing to reach the total event volume criterion set by the *PF* record. Without an *IF* record target, upstream *WR* record rights may continue to deplete stream flow during the excess pulse flow event. It is recommended that the field 13 event volume option on the *PO* record be selected if excess events are considered for satisfying the occurrence frequency criterion. The event volume criterion will exclude excess as well as target setting pulse events from consideration in satisfying the frequency criterion.

A flow regime recommendation may identify pulses of different trigger magnitudes, event volumes, frequencies, and seasons at the same location. The *PO* record LARGER EVENTS option default is to block the initiation of pulse events if another *PF* record at the same location and at any position in the priority order has engaged a pulse event with a larger magnitude trigger. Smaller pulses may continue to be tracked if they are initiated prior to the larger magnitude pulse initiation. Once the larger magnitude pulse has terminated, the smaller magnitude pulses may resume checking regulated flow for possible pulse event initiation. Multiple *PF* records assigned to the same *WR/IF* record right are processed in the order in which the records appear in the DAT file. Sequencing of *PF* records under a single water right should be considered when using the LARGER EVENTS option.

A new pulse event is eligible for initiation in the time step after the previous pulse event has terminated. The *PO* record can be used to set additional pulse event initiation criteria. An initiation option can be used to ensure that the number of days between the previous event initiation and the new event initiation equals the event duration variable on the *PF* record. A pulse event might initiate and achieve its total event volume requirement in the same day. In such a case, the event is terminated on the initiation day after setting a daily pulse target. The initiation variable on the *PO* record can be used to exclude consideration of the next pulse event until the number of days equal to the event duration has past even if the daily values of regulated flow are above the triggering criterion. Similarly, the delay variable on the *PO* record can be used to require a number of additional days between pulse termination and initiation. Initiation may also be constrained with the option to require the regulated flow of the previous day to be less than the trigger criterion. This option will tend to increase the number of separate flow events required to meet the frequency criterion, rather than allowing a single large event with a long duration to initiate multiple pulses of the same trigger magnitude.

<u>Input Records for Base Flow and Subsistence Flow Components</u>

High flow pulses and overbank pulses are only two of the four flow regime components considered in the example in this chapter. Subsistence flows and base flows are also incorporated into the final environmental instream flow requirement. Monthly or seasonal variability of the subsistence or base flow may be addressed with use coefficient *UC* records. If only one base flow component is assigned to the flow regime, a single *IF* and *UC* record pair would sufficiently provide the modeling capability to address the component. However, additional complexity is introduced by multiple levels of base flow components in conjunction with a subsistence flow. In the example in this chapter, only one of the base flow components is used at any given time for setting instream flow requirements. Selection of the base flow component is based on the state of the hydrologic condition variable. For example, during a wet hydrologic condition, the base flow component with the highest flow magnitudes might be used. Conversely, during a dry hydrologic condition, the lowest magnitude base flow and the subsistence flow components might be used conjunctively to establish an instream flow target.

Tracking the hydrologic condition can be accomplished with any combination or selection of *SIM/SIMD* input records. In the example in this chapter, the hydrologic condition is based on reservoir storage. A drought index *DI/IS/IP/IM* record set is used to adjust the target set by an accounting water right *WR* record. The target set by the *WR* record corresponds to the state of reservoir storage which is assumed to be representative of the hydrologic condition of the drainage area upstream of the flow regime's stream gage location. Alternative hydrologic conditions, if prescribed for a flow regime, could be tracked by other *SIM/SIMD* input records such as *FS/CV* records or read as independent input through *TS*, *TI*, *IN*, or *DF* records.

Switching between the relevant base flow components based on the state of the hydrologic condition can likewise be accomplished with any combination or selection of input records. In the example in this chapter, switching between the base flow components is accomplished with the *FS* record. The *FS* record continuously tracks a variable within the simulation and applies a multiplication factor when the variable falls within a specific range. In the case of activating or deactivating a specific base flow component for *IF* record target setting, multipliers of 0.0 or 1.0 are used.

<u>Example 8.1 Environmental Flow Regime Modeling</u>

The example dataset from the *Fundamentals Manual* was adapted for daily time step simulation with *SIMD* in Example 7.1. The dataset for Example 7.1 is further modified as Example 8.1 to model a hypothetical flow regime at the Hempstead control point, Hemp. The flow regime presented for this example is not the product of detailed hydrologic, biological, riparian, or geomorphic analyses that should otherwise be considered for developing a flow regime that addresses a full spectrum of environmental flow needs (TIPF, 2005).

The hypothetical flow regime for the Hempstead control point is defined by the four flow components given in Table 8.3. The flow regime includes an overbanking pulse flow event with an occurrence frequency of 1 event per 2 years, high flow pulses with an occurrence frequency of 2 pulses per season for a total potential 6 pulses per 12 months, two levels of base flow with selection based on a hydrologic condition linked to reservoir storage, and a subsistence flow that is applied conjunctively with the lowest base flow recommendation.

The overbanking pulse flow recommendation has an occurrence frequency of 1 event per 2 years. The *PF* record tracking period for this pulse event could be set for continuous tracking with a window equal to 729 days. However, in this example, the overbanking pulse flow will be tracked with a 12 month seasonal cycle spanning the months of January through December. Two seasons will be considered according to *PF* record variable SEASON COUNT. Excess flow events in the previous yearly season will be allowed to count towards satisfying the occurrence frequency. Since excess flow events do not set *PF* record targets, the *IF* record will not set targets to protect regulated flows considered to be part of the excess flow events. Therefore, the *PO* record option will be selected to exclude pulse events from consideration in meeting the occurrence frequency if the events fail to achieve the total event volume of 1,300,000 ac-ft.

The three categories of seasonal pulses are modeled without memory of the previous season. For example, each winter season will require 2 pulse events to be initiated and tracked if the regulated flow exceeds the trigger criterion. Even if more than 2 qualifying pulse events could have been tracked in the previous winter season, the count of winter pulse events resets to zero at the start of each season. Therefore, no excess pulse events are tracked for the three seasonal pulse categories. All pulse events that are initiated will set *PF* record targets and will count towards meeting the occurrence frequency criterion regardless if the event fails to achieve the total event volume criterion. Pulse events are arranged in descending order of trigger magnitude and are therefore evaluated in this order in each time step. The default *PO* record option LARGER EVENTS will block smaller pulse event initiations while a larger pulse is engaged.

New overbanking events are prohibited from initiating until at least 1 day has lapsed since the termination of the previous overbanking pulse event and the regulated flow of the previous day was below the trigger magnitude. The smaller seasonal pulses are blocked from initiation until an overbanking event has terminated. However, overbanking events can be initiated and tracked during a smaller seasonal pulse event. If a smaller seasonal pulse is engaged prior to an overbanking event, and both events are engaged on the same day, the event setting the largest *PF* record daily target will be assumed by the water right *WR* record to which the *PF* records are assigned. This is modeled using the PFTAR variable on the *PF* record.

Table 8.3
Flow Regime Recommendation at the Hempstead Control Point

Overbanking Pulse Flow

Trigger Flow	125,000	ac-ft per day
Total Event Volume	1,300,000	ac-ft per event
Maximum Event Duration	30	days
Event Occurrence Frequency	1	Event per 2 years

Winter Pulse Flow

Trigger Flow	22,000	ac-ft per day
Total Event Volume	125,000	ac-ft per event
Maximum Event Duration	15	days
Event Occurrence Frequency	2	Events, Nov. – Feb.

Spring Pulse Flow

Trigger Flow	33,000	ac-ft per day
Total Event Volume	220,000	ac-ft per event
Maximum Event Duration	20	days
Event Occurrence Frequency	2	Events, Mar. – Jun.

Summer Pulse Flow

Trigger Flow	10,000	ac-ft per day
Total Event Volume	40,000	ac-ft per event
Maximum Event Duration	10	days
Event Occurrence Frequency	2	Events, Jul. – Oct.

High Base Flow

5,700 ac-ft per day in winter season, Nov. – Feb.
6,800 ac-ft per day in spring season, Mar. – Jun.
4,000 ac-ft per day in summer season, Jul. – Oct.
Apply during Above Average Hydrologic Conditions

Low Base Flow

2,000 ac-ft per day in winter season, Nov. – Feb.
3,000 ac-ft per day in spring season, Mar. – Jun.
1,500 ac-ft per day in summer season, Jul. – Oct.
Apply during Below Average Hydrologic Conditions

Subsistence Flow

750 ac-ft per day in any season, Jan. – Dec.

The overbanking pulse events are terminated via the LOWER criterion on the *PO* record if regulated flow falls below the highest base flow recommendation of 6,800 ac-ft per day. Seasonal pulse events are terminated if regulated flow falls below the lowest base flow recommendation. Seasonal pulses are assigned a LOWER criterion of 1,500 ac-ft per day. The overbanking pulse evens are not terminated using the UPPER and CHANGE criteria. However, the seasonal pulses are terminated if regulated flow is below the season's high base flow recommendation and the flow has decreased by 5% or less since the previous day. For example, the spring seasonal pulses are assigned 6,800 ac-ft per day and 0.05 as their respective UPPER and CHANGE criteria. Use of a small fractional rate of change may aid in terminating events when storm flow conditions have subsided and the stream is under the influence of more constant base flow conditions.

The two base flow categories are selected based on upstream reservoir storage content which is used as an indicated of an above or below average hydrologic condition. Other metrics could be used, including data computed external to the simulation and read as input data such as a set of target series *TS* records, inflow *IN* records, or daily flow *DF* records. For this example, the storage in Lake Belton is used in conjunction with a set of *DI/IS/IP/IM* records to adjust a water right *WR* record target on the first day of each season. The *IM* record values allow the hydrologic condition at the start of the season to apply until the start of the next season. The *WR* record only sets a target for accounting purposes. Field 6 of the *WR* record is set to option 8. No stream flow depletions are made by this water right.

The subsistence flow is only used for instream flow target setting purposes during the below average hydrologic condition and in conjunction with the low base flow recommendation. In this example, when regulated flow is greater than the low base flow recommendation, then the daily instream flow target is set to the low base flow value for the particular season. When regulated flow is less than the subsistence recommendation, then the daily instream flow target is set to the subsistence flow value. Thus, no water is available when regulated flow is less than the subsistence recommendation. When regulated flow is less than the low base flow recommendation and greater than the subsistence recommendation, then the daily instream flow target is set to the average of the regulated flow and the subsistence flow recommendation. Thus, the instream flow *IF* record will set a target that requires 50% of the regulated flow in excess of the subsistence recommendation to remain in the stream.

The daily instream flow target is set at the Hempstead control point as the maximum of the target setting only water right *WR* records from the pulse flow components, the high base flow component, or low base flow – subsistence component. In this example, the flow regime based instream flow requirement replaces the conventional flow instream flow requirement, identified as IF-2, with a target of 120,000 ac-ft per year at the Hempstead control point as used in Example 7.1 and shown in the *Fundamentals Manual* example. The DAT file input records developed for the flow regime based instream flow requirement are provided in Table 8.4.

Table 8.4
Input Records for Environmental Instream Flow Requirement at Hempstead

```
**
**  Use coefficients to set daily base flow targets
**
UCBASE-H   5700   5700   6800   6800   6800   6800   4000   4000   4000   4000   5700   5700
UCBASE-L   2000   2000   3000   3000   3000   3000   1500   1500   1500   1500   2000   2000
**
**  All pulse flows are group under the same target setting water right.
**  The largest pulse flow target on any particular day is adopted as the WR target.
**
WR  Hemp      0.                0   8                                 HEMP-PULSES
PF     0          125000 1300000  30   1       0   1  12   2   4   2
PO     0   0   1   0   2  6800.0                   0   0   2   0
PF     0           22000  125000  15   2       0  11   2   1   4   2
PO     0   0   1   0   2  1500.0  5700.0    0.05   0   0   0   0
PF     0           33000  222000  20   2       0   3   6   1   4   2
PO     0   0   1   0   2  1500.0  6800.0    0.05   0   0   0   0
PF     0           10000   40000  10   2       0   7  10   1   4   2
PO     0   0   1   0   2  1500.0  4000.0    0.05   0   0   0   0
**
**  Drought index used to set a daily target as a proxy for the hydrologic condition.
**
WR  Hemp   100.0                0   8                              1 HYDRO-CONDITION
DW         1
DO            18
**
**  Daily target set equal to the high base flow when the hydrologic condition
**  water right sets a daily target of 50 ac-ft or greater.
**
WR  Hemp   66000  BASE-H        0   8                                 HEMP-BASE-H
FS    10             1.0     0.0    50.0   100.0   1           0   1  12   1  HYDRO-CONDITION
DW         2
DO                19
**
**  Daily targets are set equal to the low base flow and subsistence flow values.
**
WR  Hemp   26000  BASE-L        0   8                                 HEMP-LOW
DW         2
WR  Hemp     750                0   8                                 HEMP-SUB
DW         1
**
**  Daily target set equal to 0.0 if regulated flow is less than the low base flow
**  value, or equal to 1.0 if regulated flow is greater than the low base flow value.
**
WR  Hemp                        0   8                                 HEMP-ONOFF
TO     2                                                                      CONT
TO    13             SUB                                      HEMP-LOW        CONT
TO    15     1.0     MIN
DO        16
```

Table 8.4 (continued)
Input Records for Environmental Instream Flow Requirement at Hempstead

```
**
**  Daily target set equal to the greater of the average of the regulated flow and
**  subsistence flow value, and the subsistence flow value by itself.
**
WR  Hemp                   0   8                          HEMP-REGSUB
TO    2                                                           CONT
TO   13             ADD                               HEMP-SUB    CONT
TO   15     0.5     MUL                                           CONT
TO   13             MAX                               HEMP-SUB
DO       16
**
**  Daily target set equal to the low base flow value of regulated flow is greater
**  than the low base flow value and the hydrologic condition water right sets a
**  daily target less than 50 ac-ft or greater.
**
WR  Hemp                   0   8                          HEMP-BASE-L
TO   13                                               HEMP-LOW
FS   10             1.0     0.0     0.9     1.1   1          0   1  12   1  HEMP-ONOFF
FS   10             1.0     0.0     0.0   49.99   1          0   1  12   1  HYDRO-CONDITION
DO       16      19
**
**  Daily target set equal to the HEMP-REGSUB target when the value of regulated flow is
**  less the low base flow value and the hydrologic condition water right sets a
**  daily target less than 50 ac-ft or greater.
**
WR  Hemp                   0   8                          HEMP-SUBSISTENCE
TO   13                                               HEMP-REGSUB
FS   10             0.0     1.0     0.9     1.1   1          0   1  12   1  HEMP-ONOFF
FS   10             1.0     0.0     0.0   49.99   1          0   1  12   1  HYDRO-CONDITION
DO       16      19
**
**  Set a daily instream flow requirement at the Hempstead control point equal to the greater
**  of the pulse flow targets, the high base flow, the low base flow, or subsistence targets.
**
IF  Hemp       0           0 1 2           HEMP-ENVIROFLOW
TO   13             SET                               HEMP-PULSES     CONT
TO   13             MAX                               HEMP-BASE-H     CONT
TO   13             MAX                               HEMP-BASE-L     CONT
TO   13             MAX                               HEMP-SUBSISTENCE
DO       16
**
**  Set a drought index target multiplier equal to the percentage of conservation
**  storage in Lake Belton.  Field 8 of the JO record must be set to consider beginning of
**  period storage.  Update the drought index multiplier on March 1, July 1, and November 1.
**
DI    1       1  Belton
IS    2       0  457600
IP          0.0   100.0
IM   -1  -2   3  -4  -5  -6   7  -8  -9 -10  11 -12
```

Daily computations for pulse flow tracking can be obtained by using PFSMM options 1 or 3 on the *PF* record. A portion of the daily computation output records for the 2 per season winter pulse are given in Table 8.5. A complete set of daily computations are written to the SMM file for the entire period of record. The two required pulses for the winter season are both initiated and terminated in the November 1944. The low hydrologic condition is also in effect for this season with regard to setting base flow requirements. End of time step value of the regulated flow PFV variable and total event volume are shown in Table 8.5. The count variable in Table 8.5 is equal to the number of pulse flows that are being considered for meeting the occurrence frequency criterion in the current season. The second pulse event begins on November 23 and is terminated after satisfying the pulse event total volume criterion of 125,000 ac-ft at the end of the time step on November 27. The first pulse event, however, does not satisfy the total volume criterion. The pulse flows in this example are assigned the most senior priority in the simulation. The end of time step regulated flow on November 12 is equal to 5,330.2 ac-ft. The regulated flow at the priority of the pulse flow on November 13 is equal to 5,223.0 ac-ft. Since the regulated flow is less than the UPPER criterion on the *PO* record, the change in flow is computed to be a decrease of 0.0201. This is less than the CHANGE criterion, and the pulse is terminated before setting a target on November 13. Junior water rights deplete stream flow and reduce the regulated flow to 2,913.7 ac-ft by the end of the time step.

Table 8.5
Daily Pulse Flow Computation SMM File Output

```
YEAR MT DT  Regulated     Pulse Target     Event Volume      Count     Final PF Target

1944 11  1  PFV=  2079.1  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11  2  PFV=  2000.0  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11  3  PFV=  2000.0  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11  4  PFV=  2000.0  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11  5  PFV=  2000.0  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11  6  PFV= 10721.1  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11  7  PFV= 22737.7  Target= 22000.0  Volume=  22737.7  Count= 1  Final= 22000.0
1944 11  8  PFV= 27353.0  Target= 22000.0  Volume=  50090.8  Count= 1  Final= 22000.0
1944 11  9  PFV= 21365.9  Target= 21365.9  Volume=  71456.7  Count= 1  Final= 21365.9
1944 11 10  PFV=  9246.6  Target=  9246.6  Volume=  80703.3  Count= 1  Final=  9246.6
1944 11 11  PFV=  5809.5  Target=  5809.5  Volume=  86512.8  Count= 1  Final=  5809.5
1944 11 12  PFV=  5330.2  Target=  5330.2  Volume=  91843.0  Count= 1  Final=  5330.2
1944 11 13  PFV=  2913.7  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 14  PFV=  2684.0  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 15  PFV=  2127.9  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 16  PFV=  2000.0  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 17  PFV=  2000.0  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 18  PFV=  2000.0  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 19  PFV=  2000.0  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 20  PFV=  2893.1  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 21  PFV=  8987.7  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 22  PFV= 19155.1  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 23  PFV= 27676.3  Target= 22000.0  Volume=  27676.3  Count= 2  Final= 22000.0
1944 11 24  PFV= 30531.2  Target= 22000.0  Volume=  58207.4  Count= 2  Final= 22000.0
1944 11 25  PFV= 28508.6  Target= 22000.0  Volume=  86716.1  Count= 2  Final= 22000.0
1944 11 26  PFV= 22228.8  Target= 22000.0  Volume= 108944.8  Count= 2  Final= 22000.0
1944 11 27  PFV= 16055.2  Target= 16055.2  Volume= 125000.0  Count= 2  Final= 16055.2
1944 11 28  PFV=  8697.3  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 29  PFV=  5186.2  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
1944 11 30  PFV=  2995.1  Target=     0.0  Volume=      0.0  Count= 0  Final=     0.0
```

The count of pulse events that are initiated per month during the entire period of record are output to the SMM file using PFSMM options 2 or 3. Tables 8.6 and 8.7 summarize the monthly counts and show only the total number of pulse events initiated by the respective *PF* records. The overbanking *PF* record initiated and tracked a total of 46 events during the 58 years in the period of record. The overbanking *PF/PO* record pair is set to initiated and track excess pulse events. Therefore, a portion of the event initiations listed in Table 8.6 includes pulse events that did not set final *PF* record targets.

The smaller 2 per season pulse event initiations are summarized in Table 8.7. The winter, spring, and summer seasons begin on November 1, March 1, and July 1, respectively. Excess events are not considered by the seasonal *PF* records. Therefore, all initiated pulse events shown in Table 8.7 correspond to pulse events that resulted in final *PF* record targets. The 2 per season frequency requirement tends to be met early in the season as evidenced by a greater number of initiations in the first month of each season as compared to the number of initiations in the last month of each season.

Table 8.6
Number of Pulse Events Initiated by the Overbanking *PF* Record

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
6	1	0	7	13	6	0	0	1	6	2	4	46

Table 8.7
Number of Pulse Events Initiated by the Seasonal *PF* Records

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
10	12	22	23	25	11	42	18	21	13	26	21	244

Table 8.8 shows the total instream flow target set at the Hempstead control point. The monthly amounts shown are an aggregation of the daily targets. The monthly aggregated targets vary as a result of changing hydrologic conditions that cause a switch between high and low base flow requirements. Initiation of target setting pulse events contributes greatly to the monthly variability of the instream targets shown in Table 8.8.

The instream flow *IF* record at Hempstead is assigned a senior priority. Therefore it will impact water availability during the simulation. Tables 8.9 and 8.10 can be compared with Tables 7.7 and 7.8 for the daily example with the conventional instream flow requirement with a 120,000 ac-ft per year target which is distributed to 328.8 ac-ft per day. However, the Example 8.1 regulated and unappropriated flows will be significantly different than those obtained with Example 7.1. The subsistence flow alone in Example 8.1 is over two times larger than the daily instream flow targets set at Hempstead in Example 7.1

Table 8.8
Monthly Aggregated Instream Flow Target Set at Hempstead, ac-ft

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	176700	165300	210800	204000	368279	282600	132811	124000	120000	124000	1300348	122000	3330838
1941	147000	56000	472883	204000	210800	204000	154419	124000	120000	124000	219900	176700	2213702
1942	176700	159600	210800	464181	210800	204000	136000	124629	133236	124000	219900	176700	2340546
1943	248962	159600	210800	204000	210800	204000	43672	46500	42095	45202	42313	52031	1509975
1944	138558	123611	205820	204000	1011882	256400	148000	124000	140000	124000	227807	62000	2766079
1945	62000	56000	440713	204000	210800	204000	156000	124000	120000	124000	41665	270222	2013400
1946	62000	56000	210800	282600	210800	360511	124000	145636	140000	124000	233931	62000	2012279
1947	62000	56000	146200	351262	289400	204000	41266	97370	43100	31398	39687	51043	1412726
1948	47442	159004	74171	81345	74637	68018	107402	36101	30494	28615	27129	24580	758938
1949	50783	44054	93000	240000	250319	90000	46500	34219	57996	86841	60000	58777	1112489
1950	62000	183092	90512	120000	208047	172657	74132	79596	41218	35012	32981	29369	1128616
1951	30227	46442	49027	44879	72860	62758	33869	34212	30161	26417	25681	25135	481668
1952	23982	30278	41920	120000	211004	69850	28477	25108	28143	23901	36502	48152	687317
1953	159176	35984	93000	47862	1168919	57199	58407	41713	40471	76183	43750	261088	2083753
1954	47183	28095	25667	50060	259125	39045	29179	31398	25290	26943	35875	23572	621432
1955	30694	48010	37699	77086	231349	67932	45025	42978	55208	74021	22500	23250	755753
1956	25031	48365	34337	35239	74846	34515	26994	25994	22519	25916	30163	44909	428828
1957	23250	52547	70985	1241840	173970	90000	160692	124000	120000	124000	219900	241900	2643084
1958	176700	159600	517320	213340	210800	204000	157965	124000	120000	124000	69462	41199	2118386
1959	47307	145598	50932	238416	89259	90000	85016	52137	37462	1220812	170450	147121	2374511
1960	62000	58000	210800	204000	369230	308800	162530	44530	35267	46107	196177	62000	1759442
1961	62000	56000	360447	204000	210800	308800	162452	124000	120000	124000	227823	182125	2142448
1962	176700	159600	72637	58723	57717	76939	93674	27505	32090	45675	83361	122830	1007452
1963	48288	140303	40982	73401	47863	65164	36786	46500	35842	35176	45999	36381	652685
1964	34307	43587	80168	53277	57998	134258	38631	32038	65448	32475	214972	64255	851414
1965	58782	56000	93000	85827	942457	90000	124000	124000	139376	144617	159008	160304	2177370
1966	62000	56000	82781	176663	93000	85669	124000	158823	120000	124000	171000	176700	1430636
1967	176700	159600	33661	61739	71811	68185	67573	36754	41886	31989	59027	54302	863228
1968	805871	525421	393147	204000	210800	204000	168000	124000	120000	124000	99322	113180	3091741
1969	62000	156000	434165	107078	93000	90000	124000	124000	138000	124000	57085	175000	1684328
1970	60776	56000	294241	230200	304445	204000	94542	45687	74639	72578	44355	38732	1520195
1971	43535	47779	41320	41676	84298	42848	44923	59671	59342	46500	121929	214967	848786
1972	62000	58000	54422	48639	254069	60371	46500	61306	66761	38462	93625	74153	918307
1973	102000	48671	255969	180000	93000	90000	46500	46055	44545	566416	144885	85989	1704029
1974	130002	56000	78094	61460	74793	35744	46500	72906	61225	40377	100000	142000	899101
1975	50701	56000	210800	374048	359506	204000	136000	124000	138000	124000	110779	40272	1928106
1976	49140	47607	61596	180000	90481	226151	167028	44372	40671	46500	60000	155864	1169411
1977	62000	136000	93000	154248	183000	75628	124000	124000	120000	124000	38735	35561	1270171
1978	39948	142416	67743	53826	40400	56844	25154	91970	35246	29355	55034	36461	674397
1979	278263	56000	377075	124518	93000	90000	170578	124000	120000	124000	52292	53698	1663424
1980	62000	58000	93000	90000	382613	44843	39062	26023	74272	68292	22500	34645	995249
1981	35900	45763	73786	72256	93000	1214842	150879	46500	36829	37500	167000	50626	2024881
1982	38416	46463	83830	90000	160186	257413	96000	30757	28221	28015	35062	52005	946368
1983	151835	116000	266958	61532	189786	88760	38739	46500	44520	60967	33839	43729	1143165
1984	37846	37712	79555	34855	42334	34146	29812	27097	26641	667770	216414	62000	1296182
1985	54369	55348	200130	67923	225312	82809	43748	35435	34683	103213	152500	122000	1177472
1986	62000	56000	58664	64863	240038	210467	94000	76325	77419	42000	60000	132713	1174488
1987	62000	56000	372936	204000	330682	1336282	160494	124000	120000	124000	43912	163067	3097375
1988	46597	46650	70162	59515	51855	79884	45904	31201	30757	27353	24818	32509	547205
1989	62000	42112	93000	76812	358361	90000	46500	55000	60314	30139	35482	31366	981084
1990	58927	55205	285150	180000	1185462	90000	124000	124000	144000	124000	45175	40941	2456861
1991	102000	136000	93000	264200	273794	65525	31913	67112	51817	44389	120604	62000	1312354
1992	62000	58000	210800	391671	263200	204000	124000	136809	141934	124000	171000	258200	2145614
1993	201732	159600	293466	282600	210800	204000	148000	124000	120000	144542	50231	51302	1990273
1994	51761	55251	86927	54474	368620	58856	77755	46500	53160	55000	130386	102000	1140690
1995	60086	52754	198967	270000	74516	85929	99000	97038	36936	43958	38305	56065	1113554
1996	38979	44353	40736	37707	34944	48604	39270	62209	69763	42138	57884	62000	578586
1997	62000	96000	210800	1437145	289400	204000	164057	124000	120000	124000	91748	221526	3144676
MEAN	94399	88713	162678	190431	245780	170401	92178	77211	74948	114289	116073	95607	1522708

Table 8.9
TABLES Output TOU File for Example 8.1
Flow Frequency Tables Based on Aggregated Monthly Flow Volumes

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	66123.6	137151.	0.0	0.0	0.0	284.0	2186.8	6883.0	12816.	18404.	30992.	64391.	166331.	1794495.
Whit	114921.1	204744.	0.0	0.0	1717.0	3425.4	6929.0	16626.0	28719.	46163.	65837.	131747.	280970.	2981239.
WacoL	29736.0	53194.	0.0	0.0	0.0	0.0	469.0	2712.0	5984.	9936.	15246.	34506.	80009.	526505.
WacoG	161860.3	266253.	0.0	1576.8	3433.8	6300.4	10363.6	24749.0	45705.	68642.	102411.	183578.	422755.	3376485.
High	194261.6	300104.	1251.0	3561.2	6377.8	8762.8	14725.6	31658.0	60614.	89483.	125100.	232892.	488252.	3599268.
Belton	42104.7	75480.	0.0	0.0	0.0	0.0	478.6	3360.0	7761.	12757.	22410.	47585.	113249.	629618.
George	4826.8	8471.	0.0	0.0	0.0	19.8	85.8	346.0	885.	1425.	2348.	5545.	14575.	75382.
Grang	15772.4	25225.	0.0	0.0	0.0	175.4	481.4	1805.0	3652.	5489.	8552.	19998.	45534.	212283.
Camer	109858.4	170466.	0.0	494.4	1249.0	2706.4	5440.0	15032.0	28988.	44799.	65294.	130473.	290433.	1403136.
Bryan	335663.5	483897.	0.0	6558.6	11161.7	17707.0	28172.8	60717.0	107622.	158629.	232671.	402271.	810073.	4704312.
Hemp	446578.6	588542.	1634.0	13817.1	17422.0	30122.4	44643.0	89698.0	157333.	229331.	306815.	581968.	1153505.	5723481.

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	48410.7	105959.	0.0	0.0	0.0	0.0	0.0	1120.2	6568.	17213.	31404.	56010.	110911.	1596598.
Whit	79212.8	158818.	0.0	0.0	0.0	347.4	1771.1	9367.5	23665.	37116.	52853.	84756.	172639.	2492892.
WacoL	21915.1	49862.	0.0	0.0	0.0	0.0	0.0	239.7	1278.	2712.	5967.	17528.	67062.	525889.
WacoG	135123.9	211347.	147.4	3150.7	6210.8	10971.5	25718.6	45174.2	61342.	78106.	93062.	134672.	284813.	2859520.
High	165928.6	243268.	145.9	5401.8	8045.7	13061.2	30673.6	54390.8	76764.	93924.	112804.	171964.	366000.	3068948.
Belton	30822.9	51713.	0.0	0.0	0.0	0.0	0.0	1596.8	5870.	13190.	20317.	38650.	77292.	504782.
George	3284.8	6727.	0.0	0.0	0.0	0.0	0.0	36.0	167.	460.	1018.	3461.	9872.	65552.
Grang	12134.6	20399.	0.0	0.0	0.0	0.0	61.6	679.7	2628.	5051.	7792.	14465.	33105.	200098.
Camer	89371.8	133964.	0.0	268.5	503.1	1081.2	2948.1	17171.3	35595.	49961.	68087.	104685.	197384.	1392561.
Bryan	286006.2	391586.	785.3	7230.8	11864.6	19484.7	40852.7	90113.2	132647.	167296.	204720.	310302.	605494.	3859479.
Hemp	328543.2	490482.	0.0	12003.9	16008.4	26236.6	35230.9	57011.2	97342.	136694.	195497.	391512.	835151.	4733276.

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
POINT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	8400.6	62421.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	1122701.
Whit	25044.6	104171.	0.0	0.0	0.0	0.0	0.0	0.0	0.	109.	486.	2996.	42971.	1450191.
WacoL	12794.4	41807.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	471.	40270.	525889.
WacoG	59819.6	166074.	0.0	0.0	0.0	0.0	0.0	0.0	4017.	9074.	16618.	43109.	134440.	2045926.
High	83357.5	194551.	0.0	0.0	0.0	0.0	0.0	428.0	7248.	14736.	29559.	72976.	208351.	2126423.
Belton	7500.3	38381.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	346.	504782.
George	1102.0	4813.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	565.	65552.
Grang	3970.6	14934.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	9046.	200098.
Camer	47900.7	113462.	0.0	0.0	0.0	0.0	0.0	0.0	1623.	5057.	13725.	45046.	135169.	1385938.
Bryan	169546.2	362520.	0.0	0.0	0.0	0.0	0.0	456.7	14179.	32817.	65530.	182469.	478625.	3786914.
Hemp	208405.5	428359.	0.0	0.0	0.0	0.0	0.0	1095.2	16938.	37399.	77674.	232131.	609468.	4559306.

Table 8.10
Flow Frequency Tables Based on Daily Flow Volumes

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	2172.39	7436.5	0.00	0.00	0.00	0.89	15.58	91.10	226.0	386.1	638.4	1496.5	4727.9	355638.9
Whit	3775.55	10372.6	0.00	0.00	14.26	50.21	107.20	326.90	634.7	983.7	1505.2	3141.6	8701.3	381986.2
WacoL	976.93	1872.0	0.00	0.00	0.00	0.00	4.19	64.58	165.3	274.8	478.1	1046.4	2658.7	27762.4
WacoG	5317.67	12586.3	0.00	15.67	34.99	90.10	179.72	502.04	1008.9	1555.0	2347.7	4695.9	12571.2	374234.1
High	6382.16	14453.5	10.20	40.28	59.93	132.78	247.57	674.95	1295.0	1966.0	2917.9	5790.7	15275.5	398926.4
Belton	1383.29	3892.5	0.00	0.00	0.00	0.00	0.00	43.14	137.2	255.4	453.5	1091.8	3412.2	166329.9
George	158.58	534.3	0.00	0.00	0.00	0.17	1.46	7.39	18.3	31.6	52.5	129.3	370.1	28956.2
Grang	518.18	1636.5	0.00	0.00	0.00	1.97	7.95	36.96	81.4	129.4	200.2	459.0	1181.8	81543.6
Camer	3609.23	9005.6	0.00	3.51	11.78	34.38	78.16	286.63	609.5	974.9	1551.1	3398.0	8652.6	245584.4
Bryan	11027.70	23071.9	0.00	71.17	153.25	289.85	494.98	1322.87	2503.0	3745.0	5561.9	10893.0	26100.0	859923.3
Hemp	14671.64	27027.7	18.04	162.90	268.63	479.89	791.11	2042.99	3704.0	5357.0	7927.6	15501.3	36850.5	558560.6

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	1590.46	5903.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	98.5	1845.7	3642.4	261902.5
Whit	2602.41	8802.3	0.00	0.00	0.00	0.00	0.00	0.00	154.3	597.4	1213.3	2286.2	5255.4	356467.3
WacoL	719.99	1806.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	90.8	546.2	2265.4	27748.2
WacoG	4439.28	10590.6	0.00	0.00	0.00	0.00	179.17	924.68	1493.6	2025.6	2512.8	3803.1	8728.3	373769.7
High	5451.33	12514.2	0.00	0.00	0.00	91.45	302.90	1102.60	1825.8	2317.1	2903.5	4454.7	11338.6	398358.4
Belton	1012.64	2914.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	21.5	145.0	611.1	3419.1	100245.4
George	107.92	473.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.5	15.7	217.3	17136.9
Grang	398.66	1280.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	7.1	48.2	246.1	1153.6	42906.2
Camer	2936.17	7377.4	0.00	3.84	9.86	9.86	9.86	155.22	666.7	1170.6	1726.5	2977.0	6125.3	207311.5
Bryan	9396.28	19332.4	0.00	68.89	149.67	344.08	777.88	2099.29	3381.6	4346.7	5552.1	8194.9	19948.0	795495.9
Hemp	10793.77	23103.4	0.00	0.00	78.09	450.76	808.06	1500.00	2000.0	3000.0	4000.0	9457.5	27648.2	506462.7

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	275.99	3206.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	126989.8
Whit	822.80	4744.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	228.5	145089.2
WacoL	420.34	1566.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1109.1	27748.2
WacoG	1965.28	7386.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	608.2	4244.0	186373.4
High	2738.58	9081.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	1311.6	6831.3	217262.4
Belton	246.41	1738.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	47082.8
George	36.20	284.2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	16116.8
Grang	130.45	871.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	35515.2
Camer	1573.70	6123.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	491.4	3713.8	207301.6
Bryan	5570.17	17837.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	3410.0	14923.9	795495.9
Hemp	6846.84	20312.3	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	4045.8	19270.1	503462.7

Example 8.2 Environmental Flow Regime Modeling with Flood Control

The example dataset from the Fundamentals Manual was adapted for daily time step simulation with flood control reservoir capacity in Example 7.2. The dataset for Example 7.2 is further adapted as Example 8.2 incorporate the same flow regime at the Hempstead control point as used in Example 8.1. The flood control reservoirs, operating rules, and pertinent input record options are discussed with Example 7.2.

Both Example 7.2 and 8.2 use *FR* record field 6 option 2. Field 6 option 2 excludes downstream control points from consideration when the flood control reservoirs make stream flow depletions in response to downstream flooding conditions. Option 2 is highly relevant to the simulation results for Example 8.2. The flow regime at the Hempstead control point includes an overbanking pulse flow recommendation. The trigger flow rate of the overbanking pulse flow is 125,000 ac-ft per day which is equivalent to a mean daily flow rate of 63,020 cfs. When an overbanking pulse event is initiated, an instream flow target will be set with a value up to 125,000 ac-ft per day until the overbanking event is terminated. The flood flow limit established by the *FF* record at Hempstead is equivalent to 60,000 cfs. Therefore, it is possible for a senior instream flow requirement to be set with a daily target greater than the flood flow target limit. The use of *FR* record field 6 option 2 will allow the junior flood control reservoir to make upstream stream flow depletions in response to the exceedance of the downstream flood flow limit without regard for the senior instream flow requirement at the same downstream location.

The initiation of overbanking pulse events decreases from 46 to 34 events during the 58 year period of record with the introduction of flood control reservoirs in Example 8.2. This is equivalent to a 26.1% decrease in overbanking event initiations. The seasonal pulse trigger criteria are all significantly less than the flood flow limit at Hempstead. However, some seasonal pulses in Example 8.1 were initiated during the flood events that are impounded in Example 8.2. Comparing Tables 8.7 and 8.12, seasonal pulse initiations increase by 2 events to 246 events initiated during the period of record. The number of seasonal pulse event initiations per month is slightly different also as a result of flood control storage and release decisions.

Table 8.11
Number of Pulse Events Initiated by the Overbanking *PF* Record

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
4	0	0	7	8	4	0	0	1	5	2	3	34

Table 8.12
Number of Pulse Events Initiated by the Seasonal *PF* Records

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
9	14	20	26	25	11	38	21	18	17	26	21	246

Table 8.13
TABLES Output TOU File for Example 8.2
Flow Frequency Tables Based on Aggregated Monthly Flow Volumes

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											MAXIMUM
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	
PK	66123.6	137151.	0.0	0.0	0.0	284.0	2186.8	6883.0	12816.	18404.	30992.	64391.	166331.	1794495.
Whit	114921.1	204744.	0.0	0.0	1717.0	3425.4	6929.0	16626.0	28719.	46163.	65837.	131747.	280970.	2981239.
WacoL	29736.0	53194.	0.0	0.0	0.0	0.0	469.0	2712.0	5984.	9936.	15246.	34506.	80009.	526505.
WacoG	161860.3	266253.	0.0	1576.8	3433.8	6300.4	10363.6	24749.0	45705.	68642.	102411.	183578.	422755.	3376485.
High	194261.6	300104.	1251.0	3561.2	6377.8	8762.8	14725.6	31658.0	60614.	89483.	125100.	232892.	488252.	3599268.
Belton	42104.7	75480.	0.0	0.0	0.0	0.0	478.6	3360.0	7761.	12757.	22410.	47585.	113249.	629618.
George	4826.8	8471.	0.0	0.0	0.0	19.8	85.8	346.0	885.	1425.	2348.	5545.	14575.	75382.
Grang	15772.4	25225.	0.0	0.0	0.0	175.4	481.4	1805.0	3652.	5489.	8552.	19998.	45534.	212283.
Camer	109858.4	170466.	0.0	494.4	1249.0	2706.4	5440.0	15032.0	28988.	44799.	65294.	130473.	290433.	1403136.
Bryan	335663.5	483897.	0.0	6558.6	11161.7	17707.0	28172.8	60717.0	107622.	158629.	232671.	402271.	810073.	4704312.
Hemp	446578.6	588542.	1634.0	13817.1	17422.0	30122.4	44643.0	89698.0	157333.	229331.	306815.	581968.	1153505.	5723481.

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											MAXIMUM
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	
PK	46180.4	106688.	0.0	0.0	0.0	0.0	0.0	0.0	8072.	25634.	37608.	58639.	94099.	1746534.
Whit	79209.1	151059.	0.0	0.0	0.0	154.5	1717.7	12258.5	31919.	44044.	60566.	83740.	146206.	1456835.
WacoL	22093.0	48584.	0.0	0.0	0.0	0.0	0.0	449.4	1900.	3816.	6558.	18298.	66699.	400310.
WacoG	133448.2	197580.	0.0	2418.8	5885.8	10025.5	26311.8	50698.6	67801.	80813.	93190.	124026.	276968.	1795851.
High	164591.5	229793.	311.1	4810.0	6720.7	14501.4	34944.6	61922.3	81064.	94034.	110293.	159726.	359174.	2030063.
Belton	30216.5	50392.	0.0	0.0	0.0	0.0	0.0	2122.4	8099.	13269.	20643.	36199.	74616.	370740.
George	3246.3	6543.	0.0	0.0	0.0	0.0	0.0	66.0	247.	523.	1037.	3322.	9658.	52810.
Grang	12044.4	19743.	0.0	0.0	0.0	0.0	105.1	890.4	2863.	4875.	7302.	13859.	33925.	177933.
Camer	89195.3	122858.	0.0	379.5	696.2	1500.2	3843.5	20078.1	35105.	49375.	67984.	103472.	216740.	904585.
Bryan	285200.9	367129.	0.0	8687.9	10140.0	22721.0	51504.5	98719.0	131193.	162191.	199887.	304772.	632450.	2720594.
Hemp	323434.2	470294.	0.0	0.0	0.0	15177.9	26736.7	53576.4	93318.	134145.	194937.	394535.	870930.	3680776.

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											MAXIMUM
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	
PK	9829.1	57471.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	661543.
Whit	22424.9	83293.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	295.	1866.	37586.	868812.
WacoL	11664.0	37615.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	115.	35652.	389793.
WacoG	59710.6	157229.	0.0	0.0	0.0	0.0	0.0	0.0	1995.	7310.	15198.	42844.	146964.	1403259.
High	83292.9	195486.	0.0	0.0	0.0	0.0	0.0	0.0	4149.	12516.	27803.	72031.	213594.	1848849.
Belton	7855.1	33998.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	724.	319606.
George	802.9	3314.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	216.	37662.
Grang	3928.8	13161.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	10302.	96747.
Camer	47343.6	101615.	0.0	0.0	0.0	0.0	0.0	0.0	1102.	4404.	12925.	45154.	136467.	757410.
Bryan	169234.9	344516.	0.0	0.0	0.0	0.0	0.0	0.0	9686.	30235.	60911.	186100.	484200.	2702949.
Hemp	206742.5	409395.	0.0	0.0	0.0	0.0	0.0	152.4	14122.	35684.	73651.	221906.	610753.	3502187.

Table 8.14
Flow Frequency Tables Based on Daily Flow Volumes

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
PK	2172.39	7436.5	0.00	0.00	0.00	0.89	15.58	91.10	226.0	386.1	638.4	1496.5	4727.9	355638.9
Whit	3775.55	10372.6	0.00	0.00	14.26	50.21	107.20	326.90	634.7	983.7	1505.2	3141.6	8701.3	381986.2
WacoL	976.93	1872.0	0.00	0.00	0.00	0.00	4.19	64.58	165.3	274.8	478.1	1046.4	2658.7	27762.4
WacoG	5317.67	12586.3	0.00	15.67	34.99	90.10	179.72	502.04	1008.9	1555.0	2347.7	4695.9	12571.2	374234.1
High	6382.16	14453.5	10.20	40.28	59.93	132.78	247.57	674.95	1295.0	1966.0	2917.9	5790.7	15275.5	398926.4
Belton	1383.29	3892.5	0.00	0.00	0.00	0.00	0.00	43.14	137.2	255.4	453.5	1091.8	3412.2	166329.9
George	158.58	534.3	0.00	0.00	0.00	0.17	1.46	7.39	18.3	31.6	52.5	129.3	370.1	28956.2
Grang	518.18	1636.5	0.00	0.00	0.00	1.97	7.95	36.96	81.4	129.4	200.2	459.0	1181.8	81543.6
Camer	3609.23	9005.6	0.00	3.51	11.78	34.38	78.16	286.63	609.5	974.9	1551.1	3398.0	8652.6	245584.4
Bryan	11027.70	23071.9	0.00	71.17	153.25	289.85	494.98	1322.87	2503.0	3745.0	5561.9	10893.0	26100.0	859923.3
Hemp	14671.64	27027.7	18.04	162.90	268.63	479.89	791.11	2042.99	3704.0	5357.0	7927.6	15501.3	36850.5	558560.6

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
PK	1517.19	5081.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	38.4	2290.3	3478.3	224823.3
Whit	2602.29	7049.5	0.00	0.00	0.00	0.00	0.00	0.00	253.4	1027.3	1633.1	2542.3	4018.2	287270.7
WacoL	725.83	2270.4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	19.1	111.6	513.2	2089.3	39700.0
WacoG	4384.23	9579.7	0.00	0.00	0.00	0.00	131.32	1009.27	1746.5	2202.6	2672.3	3438.0	8126.9	363426.3
High	5407.40	11642.8	0.00	0.00	0.00	3.96	288.26	1279.02	2067.5	2485.0	3049.6	4119.8	10801.7	393202.4
Belton	992.71	2492.7	0.00	0.00	0.00	0.00	0.00	0.00	0.0	43.5	222.7	625.8	3173.8	29754.1
George	106.65	499.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	2.4	21.0	205.0	7930.0
Grang	395.70	1181.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	17.6	75.7	258.3	1051.7	22905.6
Camer	2930.37	6439.0	0.00	1.56	9.86	9.86	9.86	217.95	706.4	1163.5	1687.8	2943.6	6523.4	205595.3
Bryan	9369.83	17714.0	0.00	0.00	65.97	296.54	951.54	2427.31	3357.7	4172.7	5303.8	8149.4	21183.5	745473.8
Hemp	10625.92	21786.8	0.00	0.00	0.00	0.00	170.80	1160.57	2000.0	3000.0	4000.0	9600.4	28743.4	440203.1

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS
Daily Data from January 1940 through December 1997

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF DAYS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
PK	322.92	2942.1	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	88818.8
Whit	736.73	3963.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	48.9	70782.6
WacoL	383.20	1826.5	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	763.3	39700.0
WacoG	1961.70	7209.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	325.9	4242.9	195320.3
High	2736.46	8924.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	1082.9	6630.1	178525.2
Belton	258.07	1615.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	29754.1
George	26.38	175.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	6718.4
Grang	129.07	746.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	16650.2
Camer	1555.40	5323.6	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	408.9	3985.1	205585.4
Bryan	5559.95	16592.9	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	3131.8	15884.0	745422.8
Hemp	6792.20	19175.8	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	3970.0	19846.9	437203.1

REFERENCES

Goldberg, David A., _Genetic Algorithms in Search, Optimization, and Machine Learning_, Addison-Wesley, 1989.

Hoffpauir, Richard J., *Daily Time Step Simulation with a Priority-Order Based Surface Water Allocation Model*, Ph.D. Degree Dissertation, Texas A&M University, December 2010.

Hydrologic Engineering Center, *HEC-HMS Hydrologic Modeling System, Reference Manual*, CPD 74B, U.S. Army Corps of Engineers, Davis, California, September 2008.

Hydrologic Engineering Center, *HEC-DSSVue HEC Data Storage System Visual Utility Engine, User's Manual*, Version 2.0, U.S. Army Corps of Engineers, Davis, California, July 2009.

Hydrologic Engineering Center, *HEC-SSP Statistical Software Package, User's Manual*, Version 2.0, U.S. Army Corps of Engineers, Davis, California, October 2010.

Interagency Committee on Water Data, *Guidelines for Determining Flood Flow Frequency*, Bulletin 17B of the Hydrology Subcommittee, Office of Water Data Coordination, U.S. Geological Survey, Reston, Virginia, 1982.

McCuen, Richard A., _Hydrologic Analysis and Design_, Prentice Hall, 2005.

Mitchell, Melanie, _An Introduction to Genetic Algorithms_, Bradford Books, 1998.

Poff, N.L., and Ward, J.V., "Physical Habitat Template of Lotic Systems − Recovery in the Context of Historical Pattern of Spatiotemporal Heterogeneity," *Environmental Management*, Vol. 14, p. 629–645, 1990.

Ranjithan, S. R., "Role of Evolutionary Computation in Environmental and Water Resources Systems Analysis," *Journal of Water Resources Planning and Management*, ASCE, Vol. 131, No.1, January/February 2005.

Richter, B.D., Baumgartner, J.V., Powell, J., and Braun, D.P., "A Method for Assessing Hydrologic Alteration within Ecosystems," *Conservation Biology*, Vol. 10, p. 1163–1174, 1996.

Richter, B.D., Baumgartner, J.V., Wigington, R., and Braun, "How Much Water Does a River Need," *Freshwater Biology*, Vol. 37, p. 231–249, 1997.

Texas Instream Flow Program [TIFP], Texas Instream Flow Studies: Technical Overview, Texas Commission on Environmental Quality, Texas Parks and Wildlife Department, and Texas Water Development Board. TWDB Report No. 369, 2008.

Wurbs, R.A., _Modeling and Analysis of Reservoir System Operations_, Prentice Hall, 1996.

Wurbs, R.A., and W.P. James, _Water Resources Engineering_, Prentice Hall, 2002.

Wurbs, R.A., "Texas Water Availability Modeling System," *Journal of Water Resources Planning and Management*, American Society of Civil Engineers, Vol. 131, No. 4, July 2005.

Wurbs, R.A., *Comparative Evaluation of Generalized Reservoir/River System Models*, Technical Report 282, Texas Water Resources Institute, April 2005.

Wurbs, R.A., *Water Rights Analysis Package (WRAP) Modeling System Reference Manual*, Technical Report 255, Texas Water Resources Institute, 9th Edition, August 2012.

Wurbs, R.A., *Water Rights Analysis Package (WRAP) Modeling System Users Manual*, Technical Report 256, Texas Water Resources Institute, 9th Edition, August 2012.

Wurbs, R.A., *Fundamentals of Water Availability Modeling with WRAP*, Technical Report 283, Texas Water Resources Institute, Sixth Edition, September 2011.

Wurbs, R.A., *Salinity Simulation with WRAP*, Technical Report 317, Texas Water Resources Institute, July 2009.

Wurbs, R.A., *Water Rights Analysis Package (WRAP) River System Hydrology*, Technical Report 431, Texas Water Resources Institute, August 2012.

Wurbs, R.A., *Water Rights Analysis Package (WRAP) Modeling System Programming Manual*, Technical Report 388, Texas Water Resources Institute, Second Edition, August 2012.

Wurbs, R.A., R.J. Hoffpauir, and S.T. Schnier, *Application of Expanded WRAP Modeling Capabilities to the Brazos WAM*, Technical Report 389, 2nd Edition, Texas Water Resources Institute, August 2012.

APPENDIX A
INSTRUCTIONS FOR PREPARING *SIMD* INPUT RECORDS

Input records described in Chapter 3 of the *Users Manual* are applicable for both *SIM* and *SIMD*. Additional *SIMD* input records that are not included in *SIM* are covered in this Appendix. The *RT, DC, DF*, and *SC* records are stored in the *SIMD* sub-monthly input data file which has a filename extension DCF. *DW* and *DO* records may be included in either the DCF or DAT files. The other input record types listed in the table below are included in the DAT file.

SIMD Input Records Described in Appendix A

Record Identifier	Type of Information	Page Number
	Sub-Monthly Time Step Features (DAT File)	
JT	Sub-Monthly Time Step Job Control Data	214
JU	Sub-Monthly Time Step Job Options	218
TI	Sub-Monthly Time Intervals	220
C2	Control Point Output in SUB File	220
C3	Control Point Output in FFA File	220
W2	Water Right Output in SUB File	221
G2	Water Right Group Output in SUB File	221
R2	Reservoir/Hydropower Output in SUB File	221
DW	Daily (Sub-Monthly) Water Right Data	222
DO	Daily Target and Supplemental Options	225
PF	Pulse Flow Target Building Data	228
PO	Pulse Flow Supplemental Options	231
	Flood Control Operations (DAT File)	
FF	Flood Flow Limits	235
FR	Flood Control Reservoir Operations	236
FV	Reservoir Storage Volume	238
FQ	Reservoir Outflow	238
	Sub-Monthly Time Step Data (DCF File)	
DW	Listed above. Can be placed in DAT or DCF files.	222
DO	Listed above. Can be placed in DAT or DCF files.	225
SC	Selection Criteria for *DW* Record Parameters	227
RT	Routing Information for a Control Point	239
DC	Flow Disaggregation Information for a Control Point	240
DE	Net Evap-Precip Disaggregation for a Control Point	242
DH	HI Data Disaggregation for a Control Point	242
DF	Daily (Sub-Monthly) Flow or Flow Pattern Data	243

The *JT* record is the only record required to convert a *SIMD* dataset to a sub-monthly time step. The *JT* record is placed in the DAT file following the required *JD* and optional *JO* records described in the *Users Manual*. The other records covered here activate various optional features that are only available in *SIMD.*

JT Record – Sub-Monthly (Daily) Job Control Data

field	columns	variable	format	value	description
1	1-2	CD	A2	JT	Record identifier
					Number of Sub-Monthly Time Intervals
2	3-8	NTI	I6	blank,0	Default is the number of calendar days per month.
				+	Constant number of intervals in each month.
				−1	Varying number of intervals specified on *TI* record.
					Data Recorded in SUB file
3	9-12	CPOUT2	I4	blank,0	Control point output is specified only by *C2* records.
				+	First *CPOUT2* control points plus *C2* records.
				−1	Control point data is output for all control points.
				−2	Control point data is output for control points with *IN* records plus those listed on *C2* records.
4	12-16	OUTWR2	I4	blank,0	Water rights output specified by *W2* and *G2* records.
				+	First *OUTWR2* rights plus rights on *W2*/*G2* records.
				−1	All *WR*/*IF* record rights except hydropower rights.
				−2	All *WR* and *IF* record rights including hydropower.
				−3	Only non-hydropower *WR* record water rights.
				−4	Only instream flow (*IF* record) rights.
				-5	Only hydropower *WR* record water rights.
				-6	Only *FF* and *FR* record flood control rights.
					Time Block for Output to SUB File
5	17-22	BEGYR	I6	+	Beginning year.
				blank,0	*BEGYR* is assumed equal to *YRST.*
6	23-26	BEGMON	I4	+	Beginning month (1, 2, 3, ... , 12) of *BEGYR.*
				blank, 0, 1	*BEGMON* is assumed equal to 1.
7	27-32	ENDYR	I6	+	Last year to report.
				blank,0	*ENDYR* is assumed equal to *YRST+NYRS-1*
8	33-36	ENDMON	I4	+	Last month (1, 2, 3, ... , 12) of *ENDYR.*
				blank, 0, 12	*ENDMON* is assumed equal to 12.
					Annual Flood Frequency (AFF) File
9	37-40	AFF	I4	blank,0,1	No file created
				2	AFF file is created and includes all control points.
				3	AFF file is created for control points on C3 record.
					Submonthly Message (SMM) Files (Fields 10-13)
					Flow Disaggregation Assignment
10	41-44	DCSMM	I4	blank,0,1	No output.
				2	All control points are included.
				3	Only the control points included in the OUT file.
				4	Only the control points included in the SUB file.
				5	Only the control points included in the AFF file.

JT Record – Sub-Monthly (Daily) Job Control Data (continued)

field	columns	variable	format	value	description
					Routing Factor Arrays
11	45-48	RFASMM	I4	blank,0,1	No output.
				2	All control points are included. Options 2,3,4, and 5 are limited to control points paired with RT records.
				3	Only the control points included in the OUT file.
				4	Only the control points included in the SUB file.
				5	Only the control points included in the AFF file.
					Water Right Availability Period
12	49-52	APRDSMM	I4	blank,0,1	No output.
				2	All water rights are included.
				3	Only the water rights included in the OUT file.
				4	Only the water rights included in the SUB file.
					Routing Adjustments
13	53-56	RTGSMM	I4	blank,0,1	No output.
				2	All control points are included.
				3	Only the control points included in the OUT file.
				4	Only the control points included in the SUB file.
				5	Only the control points included in the AFF file.
					SUB File Size Limit
14	57-60	SUBLIMIT	I4	blank,0,1	Default limit on SUB file size.
				9	Override SUB file size limit

The *JT* record is required to incorporate a daily or other sub-monthly time step in a *SIMD* simulation. A blank *JT* record activates all defaults. The *JT* record is placed in the DAT file following the required *JD* and optional *JO* records which are described in the *Users Manual*. The optional *JU* and *TI* records follow the *JT* record. *W2*, *C2*, *C3*, *R2* and *G2* records follow the *JC*, *JO*, *JT*, *WO*, *CO*, *GO*, and *RO* records.

Explanation of JT Record Fields

Field 2: Each month may be divided into an integer number of intervals ranging from 1 to 32. For example, an *NTI* of 5 results in a time step of 1/5 month. The default is to divide February into 28 or 29 (leap year) days and the other 11 months into either 30 or 31 days. Entering –1 in *JT* field 2 means that 12 integers varying between months are provided on a *TI* record.

Fields 3 and 4: *CPOUT2* and *OUTWR2* on the *JT* record along with *W2*, *C2*, *R2*, *G2* records control sub-monthly time step output recorded in the SUB file in the same manner as *CPOUT* and *OUTWR* on the *JD* record in combination with the *WO*, *CO*, *RO*, *GO* records control monthly output written to the OUT file.

Fields 5-8: The data recorded in the SUB file covers the period extending from the beginning year and month through the ending year and month defined in *JT* record fields 5, 6, 7, and 8.

Field 9: Annual series of maximum daily naturalized and regulated flows and reservoir storage may be written to an AFF file to be read by *TABLES* to perform flood frequency analyses. The default is to not create an AFF file. A 2 in field 9 creates an AFF file containing all control points. A 3 indicates that only control points listed on a *C3* record are included in the AFF file.

Fields 10, 11, 12, 13: Fields 10 through 13 control the creation of reports that are written to the sub-monthly message SMM file. In addition to the reports controlled by *JT* record fields 10 through 13, water right selections and pulse flow output is written to the SMM file. Water right selection reports are controlled by *SC* record field 11. Pulse flow simulation reports are controlled by *PF* record field 14.

Field 10: *JT* record field 10 controls the creation of a report in the SMM file that lists the naturalized flow disaggregation method and parameters of all or selected control points. The SMM file report is created in *DC* record format for informational purposes and has no effect on the disaggregation methods and parameters assigned according to the *JU* record field 2 in the DAT file and the optional *DC* records in the DCF file.

DC records may assign a disaggregation method and disaggregation parameters automatically to all upstream control points. In many applications, one or a relatively small number of *DC* records may assign disaggregation methods and parameters too all control points in the basin. The DCSMM report allows the user to verify the disaggregation method and parameters assigned automatically to any control point.

Field 11: *JT* record field 11 controls the creation of a report in the SMM file that lists the routing factor arrays (RFAs) as described in detail in Chapter 3. *JT* record field 11 has no effect on the simulation computations, but rather simply controls whether the routing factor arrays are recorded for information purposes in the SMM file.

The routing factor arrays are generated only for control points with a non-zero routing parameter for normal flow in fields 4 and 5 of the *RT* record or for control points with a non-zero routing parameter for flood flows in fields 7 and 8 of the *RT* record. In a simulation with routing, however, every control point will utilize the routing factor array for routing changes to flow downstream to the outlet, and for conducting reverse routing if forecasting is applied. Day 0 in the routing factor array is indicative of the routing that occurs in the current time step. Days 1 or greater are indicative of the routing that occurs in future time steps.

Field 12: *JT* record field 12 controls the creation of a report in the SMM file that lists the flow availability forecast period limit for water rights. When a simulation uses forecasting by selecting JU record field 7 option 2, each water right is assigned a forecast period limit according to JU record field 9 or DW record field 2.

The limit set with DW record field 2 can be assigned automatically to a large number of water rights using *DW/SC* record pairs in the DCF file. The APRDSMM report allows the user to verify the flow availability forecast period limits assigned automatically to any water right.

Field 13: *JT* record field 13 controls the creation of a report in the SMM that lists monthly totals of the routing adjustments at control points during the simulation. *RTGSMM* has no effect on the simulation computations, but rather simply controls whether this information is recorded.

Routing adjustments are performed automatically during the simulation for any simulation that uses routing parameter *RT* records to control the downstream propagation of water right changes to stream flow. The routing parameters on an *RT* record are applied in all time steps and under all flow conditions when a change to flow is propagated downstream. When a flow depletion is routed to downstream control points, a portion of the depletion may arrive in a different time step than the flow event being depleted by the upstream water right. The *RT* record routing parameters are calibrated to routing conditions representative of flow events throughout the period of analysis. However, if flow events in the simulation are patterned with real-world gaged flow data, the flow events will vary in travel velocity according to a variety of factors including discharge rate. When flow depletions arrive at a downstream control point with no stream flow remaining, the routing computations automatically allow flow in the next time step to be decreased by the amount necessary to complete the depletion routing from the previous time step. Thus, the volume budget is maintained over the course of the period of analysis.

Field 14: *JT* record field 14 allows the user to override the file size limit on the SUB file. The SUB file is identical in format and the number of variables reported per output record. However, the SUB file contains output variables for each sub-monthly time step. As such, the SUB file for a calendar day simulation will be approximately 30 times larger than the monthly OUT simulation output file for the same number of control point, water right, and reservoir outputs. Large SUB file output file size has the potential to significantly slow down a simulation as well as consume a large amount of computer hard disk space. Caution should be exercised in overriding the SUB file size limit.

The SUB file size limit is 5 million output records when producing SUB output data in text file format. The text file format is the default option for *JD* record variable OUTFILE. Each output record in the text file is 136 ASCII characters in length. Each ASCII character is 1 byte of data. Therefore, 5 million output records will create a SUB file size equal to 680 megabytes (MB).

The SUB file size limit is 10 million output records when producing SUB output data in the binary file format. Binary SUB file output is selected with JD record OUTFILE option 2. Each output record in the binary file is 20 entries long. Each entry is 4 bytes of data. Therefore, 10 million output records will create a SUB file size equal to 800 MB.

The total number of output records to be generated during the simulation is computed as the first six lines of the SUB file plus the number of sub-monthly time steps during the simulation time block multiplied by the sum of the control point, water right, and reservoir output records specified for output by the *JT*, *C2*, *W2*, *G2*, or *R2* records. The number of sub-monthly time steps and the number of control point, water right, and reservoir output records are listed as the final four variables listed on the fifth line of the SUB file. A complete listing of SUB file variables is given in Chapter 3 Table 3.1. The number of sub-monthly time steps in the simulation time block is controlled by *JT* record fields 5 through 8.

JU Record – Sub-Monthly (Daily) Job Options

field	columns	variable	format	value	description
1	1-2	CD	A2	JT	Record identifier
					Default Monthly Flow Disaggregation Option
2	3-8	DFMETH	I6	blank,0,9	No disaggregation. Daily flows are input on *DF* records.
				1	Uniform distribution option
				2	Linear interpolation option
				3	Variability adjustment option
				4	Flow pattern option
3	9-16	VRL	F8.0	blank,0	Default = 0.10 for VRL in Eq. 3.1 used with option 3.
				+	Multiplier VRL in Equation 3.1 used with option 3.
					Multiplier for DF Record Flows
4	17-24	DFMULT	F8.0	blank,0	Default = 1.0
				+	Multiplier factor for flows from *DF* records.
					Next-Day Placement of Routed Flow Changes
5	25-28	WRMETH	I4	blank,0,1	*WR* record flow changes at beginning of sequence.
				2	*WR* record flow changes are placed in priority sequence.
6	29-32	FRMETH	I4	blank,0,1	Routed *FR* record flows at beginning of sequence.
				2	*FR* record flows are placed in priority sequence.
					Stream Flow Forecasting Parameters
7	33-36	FCST	I4	blank,0,1	No forecasting.
				2	Stream flow forecasting is activated.
8	37-40	FPRD	I4	blank,0	Simulation forecast period F_P is automatically set.
				+	Length of simulation forecast period F_P = FPRD
9	41-44	APRD	I4	blank,0	Availability forecast period limit is automatically set.
				+	Maximum limit on availability forecast period.
					Default Options for WR Record Target Distribution
10	45-48	DND	I4	blank, 0	The default is the uniform distribution.
				+	Number of days for selected-days option.
11	49-52	DSHORT	I4	blank,0	Shortages are not supplied in subsequent days.
				+	Shortages are supplied in subsequent days.

The *JU* record is placed after the *JT* record in the DAT file. If no *JU* record is provided, the sub-monthly simulation will proceed with default values for the *JU* record variables.

Explanation of *JU* Record Fields

Field 2: Daily flows may be computed within *SIMD* by disaggregating monthly naturalized flows using the various optional methods described in Table 3.2. The global default method set in *JU* record field 2 may be over-ridden for individual control points by *DFMETHOD* in *DC* record field 3. The *DFMETH* option selected in *JU* record field 2 is used for all control points that have no other option activated by *DFMETHOD* in *DC* record field 3.

Field 3: Equation 3.1 in Chapter 3 defines an upper limit *VRL* on the variability ratio *VR* used with flow disaggregation option 3. The limit is set as the daily flows from *DF* records multiplied by *VRL*. The default VRL of 0.10 may be replaced by entering a value in *JU* field 3.

Field 4: Flow quantities on *DF* records may be multiplied by a factor entered in *JU* field 4. If monthly flows are disaggregated to sub-monthly flows, units of flow on the *DF* records are irrelevant. However, if the daily flows from the DF records are used directly without activating monthly disaggregation options, *DFMULT* in *JU* field 4 may be a unit conversion factor used to convert the units of the *DF* record flows to be consistent with the other simulation quantities.

Field 5: Streamflow depletions for diversions and refilling reservoir storage for *WR* record water rights affect flows at downstream control points in future days. With the default *WRMETH* option 1, routed stream flow adjustments for streamflow depletions in preceding days are placed at the beginning of the water right priority sequence each day. Thus, actions of water rights in preceding days may affect streamflow availability in the current day for any water rights including senior rights. With *WRMETH* option 2, the routed flow changes from preceding days are inserted in the water right loop at the priority of the water right making the depletion. *WRMETH* option 2 is designed to shield senior rights in the current day from streamflow depletions by junior water rights in preceding days. The issue of volume balance violation is noted in the explanation of *NEGCP* in *JT* record field 11.

Return flows by *WR* record water rights are placed either at the beginning of the next-day simulation sequence (*RFMETH* options 1 and 3) or inserted in the water rights priority sequence (*RFMETH* options 2 and 4) based on the parameter *RFMETH* entered in *WR* record field 7.

Field 6: *FRMETH* in field 6 is the *FR* record flood control counterpart of *WRMETH* in *JU* record field 5. Routed streamflow depletions and reservoir releases from the preceding day may be placed either at the beginning of the simulation or inserted in the priority computation loop.

Field 7: *FCST* activates flow forecasting. The reverse routing forecasting methodology described in Chapter 3 is applied for all water rights if and only if *FCST* option 2 is selected.

Field 8: The default global simulation forecast period in days is set automatically by *SIMD* as twice the longest routing period in the routing factor array unless over-ridden by *FPRD*. *JU* fields 8 and 9 are ignored if forecasting is not enabled by *FCST* in field 7.

Field 9: *APRD* in *JU* record field 9 is a global maximum limit on the flow availability forecast period, which may be replaced for individual rights by *APERIOD(wr)* in *DW* record field 2. The simulation forecast period F_P is set automatically by *SIMD* subject to being replaced by the user with *FPRD* entered in *JU* record field 8. *APRD* in *JU* record field 9 and *APERIOD(wr)* in *DW* record field 2 can shorten the forecast period adopted in the water availability computations to less than F_P but cannot exceed F_P. *APRD* and *APERIOD(wr)* are maximum limits.

Fields 10 and 11: Monthly diversion, instream flow, and hydropower targets are set as specified by *WR*, *IF*, and *UC* records. The monthly target for a *WR* record is then distributed to sub-monthly (daily) intervals based on global default options specified in *JU* fields 10 and 11 which may be over-ridden for individual water rights by *DW* record fields 4 and 5. The overall default is a uniform distribution of the target over the entire month. Alternatively, a target may be distributed over the first *ND* days of the month, with or without allowing shortages to be supplied later in the month. A *DW* record is required for each *IF* record to set the *ND* variable.

TI Record – Sub-Monthly Time Intervals

field	columns	variable	format	value	description
1	1-2	CD	A2	TI	Record identifier
2	3-8	NDAY(1)	I6	+	Number of time steps in first month.
3-13	9-92	NDAY(I) I=2,12	11I8	+	Number of time steps in 2nd through 12th months.

A *TI* record is required if *NTI* in *JT* record field 2 is less than zero. The *TI* record is placed in the DAT file after the *JT*/*JO* records and before the *WO*/*CO*/*GO*/*RO* and/or *W2*/*C2*/*G2*/*R2* records. *NTI* and *NDAY* can not exceed a maximum of 32 sub-monthly time steps. Thirty-two is also the maximum number of data fields available for sub-monthly flows in each month on *DF* records.

C2 Record – Control Point Output Records to be Included in SUB File

field	columns	variable	format	value	description
1	1-2	CD	A2	C2	Record identifier
2	3-8	NCPOUT2	I6	+	Number of control point identifiers. *NCPOUT2* is entered only on the first *C2* record.
				blank,0	*C2* records are ignored if *NCPOUT2* is zero.
3-7	9-48	CPOUID2(J) J=1,5	5(2x,A6)	AN	Identifiers of control points included in the SUB file.

C3 Record – Control Point Output Records to be Included in AFF File

field	columns	variable	format	value	description
1	1-2	CD	A2	C3	Record identifier
2	3-8	NCPOUT3	I6	+	Number of control point identifiers. *NCPOUT3* is entered only on the first *C3* record.
				blank,0	*C3* records are ignored if *NCPOUT3* is zero.
3-7	9-48	CPOUID3(J) J=1,5	5(2x,A6)	AN	Control point identifiers of control points included in the AFF File.

The optional *C2*, *C3*, *W2*, *R2*, and *G2* records are placed in the DAT file following the required *JD*, optional *JO*, and required *JT* records, and the set of optional *WO*, *CO*, *GO*, and *RO* records.

The *C3* record controls which, if any, control points are included in an annual flood frequency AFF output file. *C2*, *W2*, *G2* and *R2* records control the selection of data to be output to the sub-monthly time step simulation results SUB file.

W2 Record – Water Right Output Records to be Included in SUB File

field	columns	variable	format	value	description
1	1-2	CD	A2	TI	Record identifier
2	3-8	NWOUT2	I6	+	Number of water right identifiers on *W2* records. *NWOUT2* is entered only on the first *W2* record.
				blank,0	*W2* records are ignored if *NWOUT2* is zero.
3-7	9-88	WROUT2(J) J=1,5	5A16	AN	Identifiers of water rights included in SUB file.

G2 Record – Groups of Water Right Output Records to be Included in SUB File

field	columns	variable	format	value	description
1	1-2	CD	A2	G2	Record identifier
2	3-8	NGOUT2	I6	1-5	Number of water right identifiers on *G2* records. *NGOUT2* is entered only on the first *G2* record.
				blank,0	*G2* records are ignored if *NGOUT2* is zero.
3-7	9-48	GROUP2(J) J=1,5	5A8	AN	Group identifiers for water rights included in SUB file.

R2 Record – Reservoir/Hydropower Output Records to be Included in SUB File

field	columns	variable	format	value	description
1	1-2	CD	A2	R2	Record identifier
2	3-8	NREOUT2	I6	1-5	Number of reservoir identifiers on *R2* records. *NREOUT2* is entered only on the first R2 record.
				blank,0	*R2* records are ignored if *NREOUT2* is zero.
				−1	All reservoirs are included in the output.
3-7	9-48	REOUID2(J) J=1,5	5(2x,A6)	AN	Reservoir identifiers for reservoir/hydropower projects included in SUB file.

W2, *C2*, *G2* and *R2* records specifying daily or other sub-monthly output data are analogous to the *WO*, *CO*, *GO*, and *RO* records which control monthly output data. Each of the records provides sets of identifiers used to select data to include in the simulation results, with up to five identifiers per record. All *C2* records are grouped together. All *C3* records are grouped together. All *R2* records are grouped as a set. Likewise, all *W2* are grouped together, and all *G2* records are grouped together. All are optional. It does not matter which of the four sets of records precede or follow the others. However, the complete set of *W2*/*C2*/C3/*G2*/*R2* records, if used, should follow after the complete set of *WO*/*CO*/*GO*/*RO* records, if used.

DW Record – Daily (Sub-Monthly) Data for a Water Right

field	columns	variable	format	value	description
1	1-2	CD	A2	DW	Record identifier
					Forecasting Limit in Availability Simulation
2	3-8	APERIOD(wr)	I6	blank,0	No limit on forecast period.
				+	Forecast period limit in sub-monthly time steps.
				−1	Default set by *JU* record field 8 is adopted.
				−9	Do not replace a previously set value of APERIOD
					WR/IF Record Daily Target
3	9-12	XDAY(wr)	I4	blank,0	Daily target XDAY feature is not activated.
				1	*WR*, *IF*, or *FF* record field 3 without *UC* record.
				2	Daily set using *WR/IF/FF* record and *UC* record.
				−9	Do not replace a previously set value of XDAY
					Variation in Daily Targets During Month
4	13-16	ND(wr)	I4	blank,0	ND feature is not activated.
				+	Number of days or other sub-monthly time steps.
				−1	Default set by *JU* record field 9 is adopted.
				−9	Do not replace a previously set value of ND
5	17-20	SHORT(wr)	I4	blank,0	Shortages are not supplied in subsequent days.
				+	Shortages are supplied in subsequent days.
				−1	Default is set by *JT* record field 10.
				−9	Do not replace a previously set value of SHORT
6	21-24	NDSBU(wr)	I4	blank,0	NDSBU feature is not activated.
				+	Number of days or other sub-monthly time steps.
				−9	Do not replace a previously set value of NDSBU
					Water Right Type for SC Record Consideration
7	25-28	SCTYPE	I4	blank,0,1	*WR* record type rights
				2	*IF* record type rights
				3	*FF* record type rights
					Water Right Identifier
8	29-32	DWID	A16	AN	*WR* or *IF* record water right identifier

Water rights may have *DW* and *DO* records placed in either the DAT file or DCF file or both or neither. The optional *DW* and *DO* records are included in the set of records that follow a water right *WR* or instream flow *IF* record in the DAT file and provide supporting information for a water right. The *DW* and *DO* records may be placed anyplace within the group of *SO*, *TO*, *TS*, *FS*, *WS*, *HP*, and *OR* records that follow a *WR* or *IF* record. *DW* and *DO* records can also be placed in the DCF file, where they can be paired with *SC* records. Selection criteria *SC* records following a *DW* or *DO* record in the DCF file define the characteristics of rights to which the *DW* or *DO* record applies.

DW or *DO* records in the DCF file over-write any parameters set by *DW* or *DO* records in the DAT file, except when the value of −9 is used for *DW* record fields 2 through 7 and *DO* record fields 2 through 7. Fields 8 and 9 on the *DW* record and fields 7 and 8 on the *DO* record are only read when the *DW* or *DO* records are read from the DCF file. The entry option−9 in fields 2 through 6 is applicable only for *DW* records placed in the DCF file. Similarly, the entry option −9 in fields 2 through 7 is applicable only for *DO* record placed in the DCF file.

Explanation of *DW* Record Fields

Field 2: An optional maximum limit on the forecast period (F_P) used in determining water availability in days or other sub-monthly time steps is entered in *DW* record field 2. A positive value in field 2 will limit the forecast period of the associated water rights to not exceed the value of field 2. Forecasting periods will be calculated based on longest travel time to the outlet and may be less than the value of field 2. A default global forecast period in *JU* record field 9 applies to all water rights that have no *DW* record. The *JU* record default F_P is also adopted if a −1 is entered in *DW* field 2. For a *DW* record in the DCF file, a −9 prevents the *DW* record from replacing a F_P that has been set by another *DW* record in the DAT or DCF file or the *JU* record. If the forecast period is set to zero and the simulation uses forecasting, the water right will not consider water availability information generated during the forecast simulation.

Field 3: *XDAY*=1 sets the daily target equal to the amount in field 3 of the *WR*, *IF*, or *FF* record without applying *UC* record coefficients. *XDAY* of 2 sets daily targets equal to the value in *WR/IF/FF* record field 3 distributed using the 12 monthly *UC* record coefficients. The implementation of the *XDAY* option is described in Chapter 3 under step 11 of the target building process. *XDAY* can be used in combination with the *ND* and *SHORT* options as discussed below.

Fields 4 and 5: With field 4 blank, the monthly diversion, hydropower, or instream flow target specified on the *WR* or *IF* record and *UC* records is uniformly distributed over each day (or other sub-monthly interval) of the month. The uniform distribution option is the default. The optional parameter *SHORT* in field 5 is applicable only in combination with a positive value of *ND* in field 4. The *ND* option with or without the *SHORT* option can be applied to diversion, hydropower, or instream flow targets. Global defaults for *ND* and *SHORT* are set by *JU* record fields 9 and 10 subject to being superseded for individual *WR* record water rights by *DW* record fields 4 and 5. The *ND* option is designed for applicability to multiple as well as individual water rights.

A positive *ND* activates an option in which the monthly target is uniformly distributed over the first *ND* days of the month. The daily target volume is the monthly target volume divided by *ND*. If the *SHORT* option is not activated with the *ND* option, targets are met only during the first *ND* days of the month, with shortages declared if the targets can not be met each day. The *SHORT* option allows diversion and hydropower shortages during the first *ND* days to be supplied in subsequent days of the same month that follow after the first *ND* days.

A positive value of *XDAY* is used in conjunction with *ND* to establish a daily target. *XDAY* allows the target in field 3 of a *WR* or *IF* record to be used directly as the daily target without distribution from annual to monthly targets. The implementation of the *XDAY* option is described in Chapter 3 under step 11 of the target building process. The *XDAY* daily target is established in the first *ND* days of the month if the *ND* option is activated. The *SHORT* option is applied the same as with the case for a positive value of *ND* and a zero value of *XDAY*. Remaining days at the end of the month are available for the *SHORT* option.

Field 6: Field 6 is only used for Type 2 *WR* record water rights and only when the *ND* and *SHORT* options have a positive value. *NDSBU* controls the number of days that reservoir storage will be used to meet shortages resulting from stream flow depletions that are less than the daily target. When *ND* and *SHORT* are activated with a positive value in fields 4 and 5, an attempt at recovering shortages in previous days is made in subsequent days. However, water rights with access to reservoir storage will not develop shortages if there is adequate storage supply. In order for a Type 2 *WR* record water right to develop shortages and for stream flow depletions to be used to a greater extent to meet those shortages, the access to reservoir storage as a back up source of supply must be withheld. *NDSBU* should always be set equal to or greater than *DW* record field 4, *ND*, to ensure that the entire monthly target can access reservoir storage in the situations where no stream flow depletions are possible.

When *NDSBU* is blank or 0, reservoir storage is available to meet any shortage in any day of the month for a Type 2 *WR* record water right with an associated reservoir. Shortages will only develop if reservoir storage is insufficient to back up any shortage in meeting the daily target. If *NDSBU* is positive, and *ND* and *SHORT* are positive, then the Type 2 right will not seek reservoir storage to meet daily shortages until the final *NDSBU* days of the month. Whereas the *ND* option counts days from the beginning of the month, *NDSBU* counts the number of days until the end of the month.

Fields 7 and 8: *DW* record fields 7 or 8 are used if and only if the *DW* record is placed in the DCF file. Fields 7 and 8 are not read for *DW* records in the DAT file. Likewise, *SC* records are placed only in a DCF file. A *SC* record follows the *DW* record to which it refers.

Field 7: For *DW* records placed in the DCF file, field 7 activates the *SC* record feature and specifies the type of water right to select from the set of all water rights in the DAT file. The water rights selected based on *DW* record field 7 and accompanying *SC* records are assigned the parameters on the *DW* record unless a −1 or −9 is entered in fields 2−6 for particular parameters.

Field 8: If a *DW* record is placed in the DCF file and there are no *SC* records following the *DW* record, then the water right identifier entered in field 8 is required to indicate to which water right the *DW* record parameters are to be assigned.

DO Record – Daily (Sub-Monthly) Target and Supplemental Options

field	columns	variable	format	value	description
1	1-2	CD	A2	DO	Record identifier
					Target Building Options
2	3-8	DBU(wr)	I6	blank,0,1	DBU feature is not activated.
				15	Back-up is applied as step 15 described on page 82.
				21	Back-up is applied as step 21 described on page 82.
				−9	Do not replace a previously set value of DBU.
3	9-12	DTO(wr)	I4	blank,0,1	DTO feature is not activated.
				16,17	*TO* record *TOTARGET* option applied as step 16 or 17.
				−9	Do not replace a previously set value of DTO.
4	13-16	DDI(wr)	I4	blank,0,1	DDI feature is not activated.
				18	*DI*/*IS*/*IP* record drought index is applied as step 18.
				−9	Do not replace a previously set value of DDI.
5	17-20	DFS(wr)	I4	blank,0,1	DFS feature is not activated.
				19	FS/CV record applied as steps 19 and 20 on page 82.
				−9	Do not replace a previously set value of DFS.
					Supplemental Options
6	21-24	DTSH(wr)	I4	blank,0,23	Target and shortage written to the OUT and SUB output files are based on the last target built in steps described on pages 80-82 of Chapter 3.
				1 - 12	Same as *SO* record option *ISHT*
				13	After applying *ND* to monthly target (step 13)
				14	After applying *XDAY* (step 14)
				15	After applying back-up (step 15)
				16	After applying *TOTARGET* (step 16)
				17	After applying *TOTARGET*=10 (step 17)
				18	After applying drought index (step 18)
				19	After applying options on *CV* or *FS* record (step 19)
				20	After applying options on *CV* or *FS* record (step 20)
				21	After applying back-up (step 21)
				22	After applying daily shortage recovery (step 22)
				−9	Do not replace a previously set value of DTSH
7	25-32	DAYDEP (wr)	F8.0	blank,0.0	No daily limit on stream flow depletions.
				+	Daily limit on stream flow depletions.
				−9.0	Do not replace a previously set value of DAYDEP
					Water Right Type for SC Record Consideration
8	33-36	SCTYPE	I4	blank,0,1	*WR* record type rights
				2	*IF* record type rights
				3	*FF* record type rights
					Water Right Identifier
9	37-52	DOID	A16	AN	*WR* or *IF* record water right identifier

An optional *DO* record follows its *DW* record. A *DO* record can also be used with a *WR* or *IF* record without a *DW* record. *DW* records and their associated *DO* records may be placed in either the DAT file or DCF file. *DW* and *DO* records are included in the set of records that follow a water right *WR* or instream flow *IF* record in the DAT file and provide supporting information for a water right.

Explanation of DO Record Fields

Fields 2 through 5: Options in *DO* record fields 2 through 5 control the computational sequence in the 22-step target building process described in Chapter 3 on pages 80–82.

Field 2: Activation of option *DBU* will override any placement within the target building process of the back-up option that was previously set by the *BU* record. Placing back-up within the daily target building process will result in back-up targets being created which are equal to the current daily shortage of the water right identified by the *BU* or *SO* records.

Field 3: Activation of option *DTO* will move consideration of *TO* record *TOTARGET* options to steps 16 and 17 within the target building process. Negative values of *TOTARGET* will use the previous day's value of their respective target setting variable. If the *JU*/*DW* record option *ND* is activated, *TOTARGET* options in steps 16 and 17 will applied on the first *ND* days of the month.

Field 4: Activation of the *DDI* option will move consideration of the *DI*/*IS*/*IP* drought index to step 18 within the target building process. Any step placement setting identified by *DINDEX* on the *WR* or *IF* record will be overridden by the placement specified by the *DDI* option.

Field 5: Activation of the *DFS* option will move consideration of the *FS* and *CV* record options from step 8 or 9 to step 19 or 20 of the target building process described on pages 80–82.

Field 6: The *DTSH* option is equivalent to the *ISHT* option on the *SO* record. Activation of the *DTSH* option will override any selection made on the *ISHT* option.

Field 7: The *DAYDEP* option is equivalent to the *MONDEP* and *ANNDEP* options on the *SO* record. *DAYDEP* can be used in conjunction with *MONDEP*, *ANNDEP* or *ML* records to limit the volume of stream flow depletions at the daily (sub-monthly), monthly, seasonal or annual scale.

Fields 8 and 9: *DO* record fields 8 or 9 are used if and only if the *DO* record is placed in the DCF file. Fields 8 and 9 are not read for *DO* records in the DAT file. Likewise, *SC* records are placed only in a DCF file. A *SC* record follows the *DO* record to which it refers.

Field 8: For *DO* records placed in the DCF file, field 8 activates the *SC* record feature and specifies the type of water right to select from the set of all water rights in the DAT file. The water rights selected based on *DO* record field 8 and accompanying *SC* records are assigned the parameters on the *DO* record unless a −1 or −9 is entered in fields 2−7 for particular parameters.

Field 9: If a *DO* record is placed in the DCF file and there are no *SC* records following the *DO* record, then the water right identifier entered in field 9 is required to indicate to which water right the *DO* record parameters are to be assigned.

SC Record – Water Right Selection Criteria for Assignment of DW Record Parameters

field	columns	variable	format	value	description
1	1-2	CD	A2	SC	Record identifier
					Selection Criteria
2	3-8	MASK	I6	blank,0,1	Water rights located at or above CPID in field 3.
				−1	Water rights not located at or upstream of CPID.
				2	Water rights located at or below CPID in field 3.
				−2	Water rights not located at or downstream of CPID
				3	Water rights with field 4 *UC* record identifier.
				−3	Rights with *UC* record ID not matching field 4.
				4	Water rights with annual demands greater than or equal to field 5 and less than or equal to field 6.
				−4	Water rights with annual demands less than or equal to field 5 or greater than or equal to field 6.
				5	Water rights with priority number greater than or equal to field 7 and less than or equal to field 8.
				−5	Water rights with priority number less than or equal to field 7 or greater than or equal to field 8.
				6	Type 1 *WR* record rights with: field 9 ≤ conservation storage capacity ≤ field 10
				−6	Type 1 *WR* record with conservation storage ≤ field 9 or ≥ field 10
3	11-16	CPID	2x,A6	AN	CP record field 2 identifier
4	19-24	UCID	2x,A6	AN	UC record field 2 identifier
5	25-32	D1	F8.0	+	Annual target demand, default = 0.0
6	33-40	D2	F8.0	+	Annual target demand, default = 99999999.0
7	41-48	P1	I8	+	Priority number, default = 0
8	49-56	P2	I8	+	Priority number, default = 99999999
9	57-64	S1	F8.0	+	Conservation storage capacity, default = 0.0
10	65-72	S2	F8.0	+	Conservation storage capacity, default = 99999999.0
					Optional Message SMM File Information
11	76	SCM	I4	blank,0,1	No ouput.
				2	List of identifiers of water rights meeting criteria.

SC records are only read after *DW* records which are placed in the DCF file. Field 7 of the *DW* record activates the *SC* record option and defines the type of water right that is selected when processing the *SC* record criteria. For a water right to be assigned the *DW* record parameters, the water right must satisfy all of the *SC* record criteria. An unlimited number of *SC* records can be placed after each *DW* record in the DCF file. The parameter values on the *DW* record apply to all water rights that meet all of the criteria defined by the *DW* record and associated *SC* record. The water right identifiers of those rights meeting the criteria may be included in SMM file.

PF Record – Target Developed Based on Pulse Events

field	columns	variable	format	value	description
1	1-2	CD	A2	PF	Record identifier
2	3-5	N	I3	+	Optional *CV*, *FS*, *PF* record sequential count identifier
					<u>*Flow Variable for Defining Pulse Events*</u>
3	8	PFV	I3	blank,0,1	Regulated flow at control point (field 4).
				2	Naturalized flow at control point (field 4).
				3	Unappropriated or available flow at control point.
				4	Stream flow depletion at control point (field 4).
				5	Diversion at control point (field 4).
				6	Inflow to control point excluding upstream releases.
				7	Stream flow depletion for water right (field 17).
				8	Total diversion for water right (field 17).
				9	Diversion from reservoir storage for right (field 17).
				10	Target for water right (field 17).
				11	Instream flow shortage for *IF* record right (field 17).
				12	HI data at a control point (field 4).
4	9-16	PFCP	2x,A6	AN	Control point identifier of flow variable location.
				blank	Control point from *IF*/*WR* record is the default.
					<u>*Pulse Event Initiation Criterion*</u>
5	17-24	TRIGGER	F8.0	+	Value of the daily flow trigger.
					<u>*Pulse Event Termination Criteria*</u>
6	25-32	VOLUME	F8.0	blank,0.0	Criterion not used.
				+	Total flow volume of pulse event.
7	33-36	DURATION	I4	blank,0	Criterion not used.
				+	Duration of pulse event, including initiation day.
					<u>*Pulse Event Frequency Criterion*</u>
8	37-40	FREQ	I4	+	Number of pulse events per tracking period.
				blank,0	No limit on the number of events per tracking period.
					<u>*Parameters Defining Tracking Period*</u>
9	41-48	WINDOW	I8	blank,0,+	Number of time steps not counting the current period.
10	49-52	SEASON START	I4	+	Beginning month (1, 2, … , 12) for seasonal cycle.
				blank,0	Default is continuous cycle tracking
11	53-56	SEASON END	I4	+	Ending month for seasonal cycle tracking.
				blank,0	Default is 11 months after the END month.
12	57-60	SEASON COUNT	I4	blank,0,1	Only 1 season is considered for meeting FREQ.
				+	More than one season is considered.
					<u>*PF Record Target Setting Options*</u>
13	61-64	PFTAR	I4	blank,0	*PF* record targets are not considered by *WR/IF* target.
				1	*PF* record targets are added to the preceding target.
				2	*PF* record targets replace the preceding target.
				3	Minimum of the *PF* and preceding target is adopted.
				4	Maximum of the *PF* and preceding target is adopted.

PF Record – Target Developed Based on Pulse Events (continued)

field	columns	variable	format	value	description
					<u>*Other Input*</u>
14	65-68	PFSMM	I4	0,1,2,3	Computations are recorded in the message SMM file.
15	69-84	PFWR1	A16	AN	Water right identifier for *PFV* options 7, 8, 9, 10, 11.

A pulse flow *PF* record is placed after a water right *WR* or instream flow *IF* record. Any number of *PF* records and their accompanying *PO* records may be used with any single *WR* or *IF* record. Only one *PO* record can be used with a *PF* record. The computations of the *PF/PO* record pair is the subject of discussion in Chapter 8.

<u>Explanation of PF Record Fields</u>

<u>Field 2</u>: Field 2 is identical for *CV*, *FS*, and *PF* records. *FS*, *CV*, and *PF* records are included together in the same sequential numbering with no differentiation between individual records.

<u>Fields 3, 4, and 15</u>: The pulse event is based on the variable *PFV* selected in field 3 at the control point in field 4 or for the water right in field 14. Fields 4 and 15 default to the control point and water right from the *IF/WR* record.

<u>Field 5</u>: A pulse event may be initiated when the daily value of *PFV* exceeds the trigger value in field 5. A pulse event is considered to be initiated and eligible to meet the field 8 frequency criterion on the day in which the value of *PFV* exceeds the trigger value in field 5 and no preceding pulse event is being tracked. The initiation of a new pulse event is also subject to any delay period specified by *PO* record fields 3 or 4.

<u>Fields 6 and 7</u>: When a pulse event is initiated, the pulse event is tracked until one of the termination criteria is met. The field 7 duration criterion established the maximum number of days of a pulse event. If one of the remaining termination criteria have not been met, a pulse event will terminate after the number of days in the event equals the duration criterion. A pulse event will terminate once a total cumulative volume of regulated flow, specified by field 6, has passed through the control point. The total cumulative volume of the pulse event may be measured as the summation of the daily regulated flow (default) or by the variable selected in field 3. Optional termination criteria are set with *PO* record fields 7, 8, 9, 10 and 15.

If the total event volume criterion is not used, the event duration criterion must be set to a positive number of days. Conversely, if the event duration criterion is not used, the total event volume criterion must be set to a positive value. One or both criteria may be set to positive values, but both cannot be set to zero.

<u>Field 8</u>: Each pulse event that is initiated during the tracking period will set daily pulse targets. When the number of pulse events exceeds the frequency value of field 8, no further daily pulse targets will be set for the tracking period. However, pulse events will still be initiated, tracked, and terminated when the number of pulse events exceeds the frequency. These pulse events are referred to as excess pulse events. The excess pulse flow events from the previous tracking period may be counted towards meeting the frequency value by the use of *PO* record field 12.

Fields 9, 10, and 11: Pulse events may be initiated and counted towards the field 8 frequency on a continuous or seasonal basis.

Continuous pulse event tracking is established with a number of time steps in field 9 and a blank or zero entered in field 10. Field 11 is ignored for continuous pulse event tracking. The field 9 window is the number of time steps prior to the current period in which the number of pulse flow events is considered for meeting the field 8 frequency. If the number of pulse flow events within the field 9 window is less than the field 8 frequency, a new pulse event will set daily pulse targets. If the number of pulse events within the field 9 window is greater than or equal to the field 8 frequency, new pulse events are considered to be excess events and do not set daily pulse targets. Excess pulse events may be counted towards satisfying the field 8 frequency according to *PO* record field 12.

Seasonal (or annual) pulse event tracking is engaged with field 10. The field 9 window is ignored for seasonal tracking. Seasonal tracking establishes a fixed number of months, up to a total of 12, in which pulse events are counted towards the field 8 frequency. The recorded number of pulse events resets to zero when the field 10 start month is first encountered each year. Excess pulse events in the current seasonal period may be counted towards the field 8 frequency requirement in the next season according to *PO* record field 12. The field 8 frequency requirement can be evaluated over multiple seasons according to *PF* record field 12.

Field 12: By default, the recorded number pulse events only from the current season, and optionally the excess pulse events from the previous season according to *PO* record field 12, are considered for meeting the field 8 frequency criterion. Field 12 optionally allows more than one season to be considered for meeting the frequency. If more than one season are used, then excess pulse events are not registered in the current season until all qualifying pulse events from the current and previous number of seasons attains the field 8 frequency value. The number of seasons specified in

Field 13: Field 13 provides options for including the targets developed by the *PF* record within the framework of building targets for *WR/IF* record water rights.

Field 14: Field 14 provides an option for writing the *PF* record computations to the SMM file. If field 14 us zero, no information is written to the SMM file. If field 14 is equal to 1, daily computations for the *PF* record will be written to the SMM file. If field 14 is equal to 2, the number of pulse events initiated per month and the number of events that are terminated before achieving the event volume criterion, *PF* record field 6, will be written to the SMM file at the end of the simulation in the form of tables with annual rows and monthly columns. Events enumerated in the tables may be initiated and terminated in difference months. If *PF* record field 14 is equal to option 3, the information from both option 1and 2 are written to the SMM file.

PO Record – Pulse Event Options

field	columns	variable	format	value	description
1	1-2	CD	A2	PF	Record identifier
					Priority Order Regulated Flow Options
2	3-8	REGFLOW	I6	blank,0,1	Latest regulated flow excluding reservoir releases.
				2	Latest regulated flow including reservoir releases.
				3	2nd pass or latest regulated flow including releases.
					Pulse Event Initiation Options
3	9-12	PREVIOUS EVENT	I4	blank,0, 1	Pulse initiation allowed the day after the final daily target of the previous pulse event.
				2	Pulse initiation blocked until *PF* record field 6 duration number of days since the previous pulse start.
4	13-16	DELAY	I4	blank,0	No additional days before pulse event initiation.
				+	Pulse initiation blocked until additional days since previous pulse termination.
5	17-20	LARGER EVENTS	I4	blank,0,1	Pulse initiation blocked if another *PF* record at same control point engaged an event with larger trigger.
				2	Pulse initiation does not consider other events.
6	21-24	PREVIOUS FLOW	I4	blank,0,1	Pulse initiation may occur regardless of the magnitude of the regulated flow in the previous day.
				2	Pulse initiation blocked unless regulated flow in the previous day is less than the *PF* record field 5 trigger.
					Pulse Event Termination Options
7	25-32	LOWER	F8.0	+	Lower flow threshold criterion.
				blank, 0.0	Lower threshold criterion is not used.
8	33-40	UPPER	F8.0	+	Upper flow threshold criterion.
				blank, 0.0	Upper threshold criterion is not used.
9	41-48	CHANGE	F8.0	+	Fractional change in flow expressed as a positive value between 0.0 and 1.0.
10	49-52	SEASON TERMINATE	I4	blank,0,1	Initiated pulse events may continue beyond seasonal cycle until terminated by other criteria.
				2	Pulse events are terminated at end of seasonal cycle.
					Daily Pulse Target Setting Options
11	53-56	TARGET LIMIT	I4	blank,0,1	Daily pulse targets cannot exceed the *PF* record field 5 trigger criterion.
				2	Daily pulse targets can exceed *PF* record field 5 trigger criterion.
					Pulse Event Frequency Options
12	57-60	EXCESS EVENTS	I4	blank,0,1	FREQ cannot be met by excess pulse events.
				2	FREQ can be met by excess pulse events.
13	61-64	EVENT VOLUME	I4	blank,0,1	FREQ can be met by all pulse events.
				2	FREQ cannot be met by events failing to meet the VOLUME criterion.

PO Record – Pulse Event Options (continued)

field	columns	variable	format	value	description
					<u>*Other Input*</u>
14	65-80	PFWR2	A16	AN	Water right identifier for optional pulse event target setting feature.
				blank	Option not used.
15	81-96	PFWR3	A16	AN	Water right identifier for optional pulse event termination feature.
				blank	Option not used.

A *PO* record is entered optionally after a *PF* record. If a *PO* record is not provided, the default values are adopted for the simulation.

Explanation of PO Record Fields

Field 2: Field 2 is only applicable when *PF* record field 3 is equal to 1 for tracking regulated flow. By default, regulated flows are computed only as the latest flow at the priority of the *PF* record excluding reservoir releases passing through the control point for downstream uses. Option 2 is the same as the default, except that reservoir releases for downstream uses are considered. If the default or option 2 are selected, the pulse event total volume is computed at the priority of the *PF* record but also updated at the end of the time step. If the regulated flow at the end of the time step is different than the regulated flow considered at the priority of the *PF* record, the total volume will be adjusted accordingly for consideration against the *PF* record field 6 total volume termination criterion.

Option 3 considers regulated flow as the amount computed for the second pass instream flow option. Reservoir releases are considered with option 3. If the second pass instream flow option is not selected for the simulation, the regulated flow is equal to the regulated flow at the priority of the *PF* record. Total event volume is not adjusted at the end of the time step with option 3.

Field 3: The default option is for pulse events to be eligible to initiate immediately after the last target set by the previous pulse event. Field 3 optionally allows a pulse event to initiate only after the *PF* record field 7 duration number of days has lapsed since the start of the previous pulse event.

If the *PF* record field 7 pulse event duration criterion is not used, then *PO* record field 3 must be set to option 1. *PO* record option 2 can only be used to control sequential pulse event initiations when the pulse events have a specified number of days of duration.

Field 4: The number of additional days before a pulse event can initiate is entered in field 4. The days of delay are counted after the option set by field 3.

Field 5: All other *PF* records at the same control point are automatically checked if those *PF* records have engaged a pulse event with a higher trigger magnitude. If larger pulse events at the same control point are engaged, the smaller pulse event of the *PF* record being considered will be blocked from initiation until the larger event(s) have been terminated. *PF* records at the same control point and of the same priority number should be arranged in order of descending trigger magnitude to ensure larger pulses are engaged prior to smaller pulses.

Field 6: Pulse event initiation can occur, by default, regardless of the value of regulated flow in the previous day. Option 2 blocks pulse event initiation unless the regulated flow in the previous time step is less than the trigger criterion set by *PF* record field 5.

Fields 7, 8, 9 and 15: Additional termination criteria may optionally be set with fields 7, 8, 9, and 15. If daily regulated flow is less than the lower threshold of field 7, the pulse event terminates immediately. No daily pulse targets are established for the time step. If daily regulated flow during the pulse event is less than the regulated flow of the preceding time step and the daily regulated flow is below the field 8 upper threshold, the fractional decrease in flow is calculated. If the fractional decrease of regulated flow from the preceding to current time step is less than value of field 9, the pulse event will terminate immediately. Pulse events will terminate immediately if any target is set by the water right identified in field 15 in the current time step.

Field 10: By default, a pulse event will continue to be tracked and to set daily pulse targets beyond the *PF* record field 11 end of season month until one of the termination criteria are met. Optionally, any initiated pulse events can be terminated on the last day of the last month of the season.

Field 11: Daily pulse targets are by default limited to not exceed the value of the *PF* record field 5 trigger criterion. Field 11 optionally allows the daily pulse targets to equal the total daily regulated flow, subject to the cumulative daily pulse targets not exceeding the *PF* record field 6 volume criterion.

Field 12: By default, excess pulse events do not count towards meeting the *PF* record field 8 frequency criterion. Field 12 optionally allows the excess events to count towards meeting the frequency criterion even though no daily pulse targets are used to set final *PF* record targets during the excess events. Excess events are only tracked when field 12 option 2 is selected.

Field 13: By default, all pulse events that set daily targets or pulse events that are considered excess will be counted towards meeting the *PF* record field 8 frequency criterion. However, field 13 optionally allows only those events which have satisfied the *PF* record field 6 volume criterion to be counted towards meeting the frequency. The selection of the field 13 option does not affect the pulse event termination criteria.

Field 13 option 2 can only be used when the *PF* record field 6 total event volume is set to a positive value. If the *PF* record field 6 total event volume criterion is set to zero, all pulse events are terminated according to criteria other than a total event volume.

Field 14: Daily targets developed from pulse event tracking will not be used to set a *PF* record target if any target is set by the water right identified in *PO* record field 14 in the current time step. This option has the same effect as temporarily switching to *PF* record field 13 option 0. *PF* record targets will resume being set according to the user selection of *PF* record field 13 when the water right identified in *PO* record field 14 sets a target equal to zero.

Field 15: If a pulse event is engaged, any target set by the water right identified in field 15 will terminate the pulse immediately. No *PF* record target will be set in the current time step and pulse event tracking will resume according to the initiation criteria and options.

The *PF* and *PO* record variables are assigned to arrays automatically at the beginning of the simulation. The following tables provide the array names which contain the *PF* variables. The array assignment does not affect the simulation and is provided here for informational purposes only. The arrays that hold values of the *FS/CV* record variables are used also for *PF/PO* records.

PF Record Variables and Corresponding Program Array Elements

field	*PF* record variable	program array	field	*PF* record variable	program array
3	PFV	FSI(FS,1)	10	SEASON START	FSI(FS,6)
4	PFCP	FSI(FS,2)	11	SEASON END	FSI(FS,7)
5	TRIGGER	FSX(FS,1)	12	SEASON COUNT	FSI(FS,17)
6	VOLUME	FSX(FS,2)	13	PFTAR	FSI(FS,8)
7	DURATION	FSI(FS,3)	14	PFSMM	FSI(FS,9)
8	FREQ	FSI(FS,4)	15	PFWR1	FSWR(FS,1)
9	WINDOW	FSI(FS,5)			

PO Record Variables and Corresponding Program Array Elements

field	*PO* record variable	program array	field	*PO* record variable	program array
2	REGFLOW	FSI(FS,10)	9	CHANGE	FSX(FS,5)
3	PREVIOUS EVENT	FSI(FS,11)	10	SEASON TERMINATE	FSI(FS,13)
4	DELAY	FSI(FS,12)	11	TARGET LIMT	FSI(FS,14)
5	LARGER EVENTS	FSI(FS,16)	12	EXCESS EVENTS	FSI(FS,15)
6	PREVIOUS FLOW	FSI(FS,19)	13	EVENT VOLUME	FSI(FS,18)
7	LOWER	FSX(FS,3)	14	PFWR2	FSWR(FS,2)
8	UPPER	FSX(FS,4)	15	PFWR3	FSWR(FS,3)

FF Record – Flood Flow Limit

field	columns	variable	format	value	description
1	1-2	CD	A2	FF	Record identifier
2	3-8	CP	A6	AN	Control point identifier
3	9-24	AMT	F16.0	+	Annual flood flow limit volume.
4	25-32	USE	2x,A6	blank,0 +	Default is uniform based on number days in month. Monthly distribution identifier (*UC* records).
5	33-40	CPERIOD(wr)	I8	blank,0 + −	Forecast period is set automatically within *SIMD*. Forecast period in number of time steps such as days. Forecasting not applied for flow capacity at this cp.
6	41-48	DINDEX(wr)	I8	blank,0 +	Default is to not apply flood (drought) index. Flood index to connect to *DI/IS/IP* records.
7	49-64	WRID(wr)	A16	AN	Water right identifier (optional)

Flood control reservoir operations are described in Chapter 5. Reservoir operations for *FR* record flood control are based on emptying flood control pools as expeditiously as possible without contributing to river flows exceeding flow limits specified on *FF* records. Any number of *FR* record reservoirs may operate for any number of *FF* records at downstream control points. *FR* and *FF* records are treated as types of water rights analogously to water right *WR* and instream flow *IF* records and placed in the DAT file with the *WR* and *IF* records. The same rules for organizing the DAT file are applicable to *FR*, *FF*, *WR*, and *IF* records.

<u>Explanation of FF Record Fields</u>

<u>Field 2</u>: The *FF* record flood flow limit is applied to regulated flows at this control point.

<u>Field 3</u>: The annual equivalent volume from which daily flow limits are computed is entered in the 16-character field 3. This annual flow volume is converted to monthly and then daily flows within the *SIMD* simulation. The daily flow volume represents an allowable or non-damaging flow level at this control point. Release and impoundment decisions for upstream reservoir flood pools with gated controls are based on maintaining regulated flows below this limit.

<u>Field 4</u>: The default is to distribute the annual flow limit uniformly over the days of the year. An identifier in field 4 connects to monthly coefficients on *UC* records used to distribute the annual volume to the 12 months of the year. Monthly volumes are uniformly distributed to daily.

<u>Field 5</u>: The default sets channel capacity forecasting periods automatically as the travel time between each upstream *FR* record flood control reservoir and this downstream *FF* record control point. A positive *CPERIOD(wr)* in field 5 serves as an upper limit on the number of days in the forecasting periods used to determine the available channel capacity. A negative integer in field 5 indicates no forecasting, meaning only the current day regulated flow is used to compute the available channel capacity at this control point.

<u>Field 6</u>: A flood index on a *FR* record is the same as a drought index on a *WR* record and connects the flow limit to a *DI/IS/IP* record storage-percentage target table.

FR Record – Flood Control Reservoir Operations

field	columns	variable	format	value	description
1	1-2	CD	A2	FR	Record identifier
2	3-8	CPID	A6	AN	Control point identifier for location of reservoir
3	9-16	FCSTORE	I8	+	Storage priority number
4	17-24	FCREL	I8	+	Release priority number
5	25-28	FFNUM	I4	+	Number of *FF* record limits, default is all *FF* records.
6	29-32	FCDEP	I4	blank,0,1	Downstream control point limit option is not activated.
				2	Downstream control points are excluded in determining availability for making flood control depletions.
7	33-40	FCMAX	F8.0	+	Maximum flood pool release volume per time step.
				blank,0	Limit on flood pool releases is not activated.
					Storage Volumes
8	41-48	FCTOP	F8.0	+	Total storage capacity at top of flood control pool.
9	49-56	FCGATE	F8.0	+	Storage capacity activating *FV/FQ* record table.
10	57-64	FCBOTTOM	F8.0	+	Storage capacity at bottom of flood control pool.
					Multiple-Reservoir System Balancing Index
11	65-72	FCMUL	F8.0	+	Multiplier factor M, default = 1.0
12	73-80	FCADD	F8.0	+	Addition factor A, default = 0.0
					Water Right Identifiers
13	81-96	WRID(wr)	A16	AN	Water right identifier for storage right (optional)
14	97-112	WRID(wr)	A16	AN	Water right identifier for release right (optional)

The use of *FR* and *FF* records to model reservoir operations for flood control is described in Chapter 5. *FR* and *FF* records are treated as types of water rights analogously to water right *WR* and instream flow *IF* records and placed in the DAT file with the *WR* and *IF* records. The same rules for organizing the DAT file are applicable to *FR*, *FF*, *WR*, and *IF* records.

A single *WS* record must accompany each *FR* record to provide the pertinent information for establishing a reservoir. A single *WS* record may be provided for each *FR* record, or optionally a consecutive group of *FR* records may share a single *WS* record placed after the *FR* record group. *WS* record fields 3, 7, and 11 are relevant for conservation reservoirs. However, these three fields are ignored when a *WS* record is read following a *FR* record. The default setting for *WS* record field 8 is to assume the flood control pool is empty at the beginning of the simulation.

FF records only result in establishing a daily target which serves as a regulated flow limit to be monitored by any upstream *FR* record flood control pool. *FF* records may be associated with any of the optional *TO/LO/TS/FS/CV/PF/PO/BU* target building records. *FR* records are only associated with a single *WS* record. Optional target building, supplemental, or priority circumvention records are relevant to conventional target setting and water supply operations and therefore are not associated with flood control *FR* records.

The primary source of output for analysis of flood control operations are the storages written to the OUT and SUB file for control points. The optional AFF file is also relevant for flood frequency and flood control analysis with Tables Job 7 records. However, output for individual *FF* and *FR* records may be written to the SUB file. *FF* and *FR* record output is not written to the OUT file. *JT* record field 4 option -6 writes output to the SUB file for all *FF* and *FR* records. Additionally, *JT* record field 4 options 0 and 1 may be used in conjunction with a *W2* record to specify certain *FF* and *FR* records for output to the SUB file.

Explanation of FR Record Fields

Field 2: The reservoir is located at the control point with this identifier. *FR* record field 3 is equivalent to *WR* or *IF* record field 2.

Fields 3 and 4: Storage and release priorities control the order in which the water right simulation computations are sequenced. Low priority numbers are senior to larger numbers. The release priority must be junior to the storage priority.

Field 5: The default is for operation of the reservoir to be based on all *FF* record control points at and downstream of the reservoir. An integer in *FR* record field 6 limits the number of *FF* record control points considered. The control points nearest the reservoir are considered.

Field 6: The default is for the flood control pool to be filled with stream flow depletions using the standard computation of water availability which includes consideration of water at downstream control points. If the *FR* record field 7 option is activated (FCDEP=2), downstream control points are excluded from the water availability computation, and the flood control reservoir may deplete all stream flow at the reservoir's control point.

Field 7: Sub-monthly time interval (daily) release volumes from the controlled flood control pool are constrained to not exceed this maximum limit. FCMAX in *FR* record field 8 is applied within *SIMD* in the same manner as the daily flow rate (volume/day) limit derived from the annual (volume/year) limit AMT entered in *FF* record field 3 except FCMAX applies only to releases from the controlled flood control pool of this reservoir without considering forecasting.

Field 8: The top of the flood control pool is the maximum cumulative storage volume to which inflows can be stored. If this level is exceeded, outflow equals inflow.

Field 9: A positive non-zero *FCGATE* entered in field 10 is required to activate routing with a storage-outflow table defined by *FV* and *FQ* records. The *FV/FQ* record storage-outflow relationship governs uncontrolled outflows if the storage rises above the level of *FCGATE*. Otherwise, *FC* and *FF* record release rules determine releases from controlled flood control storage. If *FCBOTTOM* is greater than zero and *FCGATE* is left blank, the entire flood control pool, defined as the capacity between *FCBOTTOM* and *FCTOP*, is assumed to be a controlled pool. If *FCBOTTOM* is zero and *FCGATE* is left blank, the entire pool is uncontrolled.

Field 10: Controlled flood control releases are not made if storage content falls below this level.

Fields 11 and 12: For purposes of flood control operations, multiple-reservoir systems are comprised of reservoirs that have the same priority number entered in fields 4 and/or 5 of their *FR* records. The rank index is used to sequence simulation of each reservoir of a multiple reservoir system.

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

The parameters M and A in *FR* record fields 12 and 13 are applied in multiple-reservoir release decisions for flood control pools in an analogous manner to applying the parameters M and A in *OR* record fields 5, 6, 7, and 8 in multiple-reservoir release decisions for conservation pools. However, whereas conservation pools may be subdivided into two zones, flood control pools are always treated as a single zone.

Fields 13 and 14: Flood control storage and release operations are assigned separate priority numbers in fields 3 and 4. As such, a single *FR* record is simulated as two separate water rights within *SIMD*. Fields 13 and 14 allow for assignment of independent identifiers for the storage and release rights associated with each *FR* record.

FV Record – Reservoir Storage Volume for Storage versus Outflow Table

field	columns	variable	format	value	description
1	1-2	CD	A2	FV	Record identifier
2	3-8	RES	A6	AN	Reservoir identifier
3	9-104	TARA(I) I=1,12	12F16.0	+	Reservoir storage volumes corresponding to outflows in same fields of *FQ* record.

FQ Record – Reservoir Outflow for Storage versus Outflow Table

field	columns	variable	format	value	description
1	1-2	CD	A2	FV	Record identifier
2	3-8	RES	6x		Field is not used.
3	9-104	TARB(I) I=1,12	12F16.0	+	Reservoir outflows corresponding to volumes in same fields of *FV* record.

Pairs of *FV* and *FQ* records are grouped together in the DAT file following the set of all *WR*, *IF*, *FR*, and *FF* records. A *FQ* record must follow each *FV* record. The set of all *FV* and *FQ* records is placed before the set of all *SV* and *SA* records.

A pair of *FV* and *FQ* records must be supplied for reservoirs with uncontrolled storage, as established by a positive value in field 9 of a *FR* record connected to the reservoir. A *FV/FQ* table is supplied only once, even though flood control reservoirs may have multiple controlled storage pools, each with different operations. The uncontrolled pool of a flood control reservoir has only one set of operations logic as defined by one *FV/FQ* table.

RT Record – Routing Information for a Control Point

field	columns	variable	format	value	description
1	1-2	CD	A2	RT	Record identifier
2	3-8	RTID	A6	AN	Control point identifier corresponding to *CP* record.
					<u>*Routing Parameters for Normal Flows*</u>
3	9-12	RTPYE(cp,1)	I4	blank,0 1 2	Routing is not performed at this control point. Lag and attenuation method is applied. Muskingum method is applied.
4	13-20	RPARAMS (cp,1)	F8.0	+	Lag or Muskingum *K* for the stream reach below this control point.
5	21-28	RPARAMS (cp,2)	F8.0	+	Attenuation or Muskingum *X* for the stream reach below this control point.
					<u>*Routing Parameters for Flood Flows*</u>
6	29-32	RTPYE(cp,2)	I4	blank,0 1 2	Routing is not performed at this control point. Lag and attenuation method is applied. Muskingum method is applied.
7	33-40	RPARAMS (cp,3)	F8.0	blank,0 +	Parameter in field 4 is also applicable to flood flows. Lag or Muskingum *K* for the stream reach below CP.
8	41-48	RPARAMS (cp,4)	F8.0	blank,0 +	Parameter in field 5 is also applicable to flood flows. Attenuation or Muskingum *X* for the stream reach.

RT, *DC*, and *DF* records are stored in a DCF file. The set of all *RT* records is followed in the DCF file by the set of all *DC* records, which is followed by the set of all *DF* records.

Fields 3, 4, and 5 are applicable to routing of all flow adjustments (flow changes) except those associated with *FR* record reservoir operations for flood control. Fields 6, 7, and 8 are applicable to routing flow adjustments associated with flood control operations defined by *FR* records.

<u>Explanation of RT Record Fields</u>

<u>***Field 2***</u>: The data provided on the *RT* record is for the control point with this identifier. The routing computations are for the river reach below this control point.

<u>***Field 3***</u>: The default is no routing at this control point. The lag-attenuation routing method or the Muskingum routing method can be activated. The parameters for either method are entered in fields 4 and 5.

<u>***Fields 4 and 5***</u>: Routing parameters are for the reach downstream of control point RTID. Only non-flood control related changes to flow are routed downstream with these parameters. The lag time parameter for the lag-attenuation method or the parameter K for the Muskingum method is entered in field 4. The corresponding attenuation time or Muskingum X is entered in field 5.

<u>***Fields 6, 7, and 8***</u>: Routing specifications for *FR* record flood releases and filling of flood control pools are entered in fields 6, 7, and 8.

DC Record – Disaggregation Information for Naturalized Flow at a Control Point

field	columns	variable	format	value	description
1	1-2	CD	A2	DC	Record identifier
2	3-8	CPID	A6	AN	Control point identifier corresponding to *CP* record.
					Method for Disaggregation
3	9-16	DFMETHOD	I8	blank,0	Default is specified in *JU* record field 2.
				-1, 1	Uniform distribution option.
				-2, 2	Linear interpolation option.
				-3, 3	Variability adjustment option.
				-4, 4	Flow pattern option.
				-5, 5	Drainage area ratio transfer option.
				-6, 6	Regression equation transfer option.
				8	No disaggregation. *IN* records in volume/day units.
				9	No disaggregation. Daily flows input on *DF* records.
					Source and Temporal Range of Pattern
4	17-24	DFID	2x,A6	AN blank	Control point identifier on *DF* records of source gage. Default is *CPID* in *DC* record field 2
5	25-32	BEGYR	I8	+ blank,0	Beginning year of the pattern. Default = first year of simulation
6	33-40	BEGMT	I8	+,blank,0	Beginning month of the pattern. Default = 1
7	41-48	ENDYR	I8	+ blank,0	Ending year of the pattern. Default = last year of simulation
8	49-56	ENDMT	I8	blank,0,+	Ending month of the pattern. Default = 12
					Flow Lag Option
9	57-64	LAG	I8	+,−	Phase shift in units of time steps. Default = 0
					Coefficients for DFMETH Options 5 and 6
10	65-72	X	F8.0	+,blank,0	Exponent for *METH* options 5 and 6. Default = 1.0
11	73-80	M	F8.0	+,blank,0	Multiplicative coefficient for option 6. Default = 1.0
12	81-88	A	F8.0	+,blank,0	Additive coefficient for *METH* option 6. Default=0.0

All *RT*, *DC*, *DE*, and *DH* records are placed in the DCF file before the complete set of *DF* records. The DCF file ends with an *ED* record after the complete set of *DF* records.

Explanation of DC Record Fields

Field 2: The data provided on the *DC* record is for the control point with this identifier.

Field 3: Sub-monthly flows may be input on *DF* records, with no monthly flows provided (option 9). Alternatively, monthly flows may be disaggregated using various optional methods. Alternative flow disaggregation options are outlined in Table 3.2. If *DC* record field 3 is blank, the default option defined in *JU* record field 2 is adopted for this control point. If *DC* field 3 is set to 9 for no disaggregation, fields 4 through 12 are ignored. The *DF* records are expected to cover the entire hydrologic period-of-record when *DC* record field 3 is set to option 9.

All control points upstream of the control point in field 2 are automatically assigned the absolute value of field 3 DFMETHOD when field 3 is equal to -1, -2, -3, -4, -5, or -6. Fields 5 through 12 are also automatically assigned without alteration to all upstream control points. If DFMETHOD is equal to -3, -4, -5, or -6, the value of field 4 DFID is automatically computed for the upstream control points. Automatic computation of DFID for the upstream control points occurs according to the following selection process:

1. The control point identifier of the upstream control point is selected as DFID if DF records are provided at this location.
2. DFID is equal to the control point identifier of the first downstream control point where DF records are provided.
3. DFID is equal to the control point identifier of an upstream location where DF records are provided. If there are multiple upstream DF record locations, the upstream location with the fewest number of intervening control points is selected.
4. DFID is equal to the control point identifier of a location where DF records are provided and that shares a common downstream confluence with the control point being assigned DFID. If there are multiple confluent DF record locations, the DF record location with the fewest number of intervening control points is selected.

Multiple DC records with negative DFMETHOD may be used within the same basin. Each DC record read from the DCF file with overwrite the parameter assignment of previous DC records where there is an overlap in control points.

Fields 4-8: Disaggregation options 3, 4, 5, and 6 are based on flow amounts from *DF* records. *DC* record fields 8–12 define the flow sequences from the *DF* records that are used to develop flow patterns for use in the disaggregation computations.

Field 9: Disaggregation options 4, 5, and 6 activated in field 3 are based on a pattern established using flows from *DF* records. *LAG* in field 9 is used to shift the time series forward or backward in time. *LAG* > 0 is used for transferring a pattern to a downstream destination from an upstream source. The time series at the upstream source is shifted forward in time, with the value at time step *T* at the source becomes the value at time step *T+LAG* at the destination. Likewise, *LAG* < 0 is used for transferring a downstream source pattern to an upstream destination by shifting the pattern earlier in time. The pattern is first checked for the need to repeat. Then during shifting, the values at the trailing end of the shift in the array are set equal to the last value of the trailing end. Values at the leading end of the shift in the array are lost.

Fields 10-12: Disaggregation options 5 and 6 activated field 3 are based on transferring a pattern established using flows from *DF* records from a source control point to a destination control point using one of the following equations (Eqs. 3.6 and 3.7) with parameter values provided in fields 10-12.

$$P_{destination} = \left[P_{Source} \left(\frac{Area_{destination}}{Area_{source}} \right) \right]^{X}$$

$$P_{destination} = A + M \left(P_{source} \right)^{X}$$

DE Record – Disaggregation Information for Net Evaporation-Precipitation at a Control Point

field	columns	variable	format	value	description
1	1-2	CD	A2	DE	Record identifier
2	3-8	CPID	A6	AN	Control point identifier corresponding to *CP* record.
					Method for Disaggregation
3	9-16	DEMETHOD	I8	blank,0,1	Uniform distribution, default.
				8	No disaggregation. *EV* records in units of depth/day.

DH Record – Disaggregation Information for HI Data at a Control Point

field	columns	variable	format	value	description
1	1-2	CD	A2	DH	Record identifier
2	3-8	CPID	A6	AN	Control point identifier corresponding to *CP* record.
					Method for Disaggregation
3	9-16	DHMETHOD	I8	blank,0,1	Uniform distribution, default.
				8	No disaggregation. *HI* record value repeated daily.

The *DE* and *DH* records are placed in the DCF along with the *RT* and *DC* records prior to any *DF* records that may be included as the last entries in the DCF file. If no *DE* or *DH* records are provided, the default option is to uniformly distribute monthly net evaporation-precipitation and *HI* control point data. The disaggregation method entered in *JU* record field 2 applies only to naturalized flows at a control point.

Explanation of DE and DH Record Fields

Field 2: The data provided on the *DE* or *DH* record is for the control point with this identifier.

Field 3: If no *DE* or *DH* records are provided, the default option is to uniformly distribute monthly net evaporation-precipitation and *HI* control point data. Uniform distribution is performed by dividing monthly by the number of days being simulated per month. The uniform distribution is likely to be applicable in nearly all cases for net evaporation-precipitation disaggregation.

Option 8 involves repeating the value entered on the *EV* or *HI* record for each day of the month. This option should be used with caution. Option 8 should only be used in instances when the value entered on the *EV* or *HI* record is known to represent a constant daily amount during the month. Option 8 is more likely to be applicable to *HI* control point data that represents a constant state variable rather than a daily quantity that has been aggregated to a monthly volume and entered in the HIS file.

DF Record – Daily (Sub-Monthly) Flow Record

First *DF* Record for a Particular Month and Control Point

field	columns	variable	format	value	description
1	1-2	CD	A2	DF	Record identifier
2	3-10	DFID	2x,A6	AN	Control point identifier of the location for the flow pattern. *DFID* is entered on the first *DF* record only.
3	11-20	YEAR	2x,I8	+	Year for the *DFLOW* values.
4	21-30	MONTH	2x,I8	+	Month for the *DFLOW* values.
5	31-40	NUM	2x,I8	blank,0	By default, *NUM* is set to 4 to accommodate the default calendar day daily simulation.
				+	Number of *DFLOW* data records to follow. *NUM* is an integer between 1 and 4.

Second, Third, Fourth, and Fifth *DF* Records for a Particular Month and Control Point

field	columns	variable	format	value	description
1-8	1-80	DFLOW(J) J=1,8	8F10.0	+	Flow or flow pattern for sub-monthly time steps. Up to 8 flow values are entered on each record.

DF records are placed in the DCF file after the complete set of *DC* records. The DCF file ends with an *ED* record after the complete set of *DF* records. Unlike other *SIM* and *SIMD* input records, the *DF* records are organized with field widths of 10 characters.

A set of up to five DF records is required to enter flows for one month at one control point. The parameter NUM in field 5 of the first *DF* record is the number of additional records required to contain the flows for each sub-monthly interval given that 8 flows can be entered on each record. With a daily time step, five *DF* records are required for each month at each control point. The first record provides the control point identifier and the year and month. The second, third, and fourth records contain flows for the first eight days, days 9 through 16, and days 17 through 24. The fifth record contains the flows for the remaining days of that month.

An example of a set of *DF* records with 31 daily flows for the month of December 1974 is as follows.

```
DF    CP-1      1974        12         4
     236.0     238.0     237.0     228.0     212.0     208.0     777.0     943.0
     421.0     286.0     958.0     734.0     459.0     316.0     265.0     244.0
     217.0     191.0     176.0     241.0     393.0     375.0     456.0     465.0
    1096.0    1618.0    1713.0    1647.0    1241.0     837.0     880.0
```

DFLOW values can be either actual sub-monthly naturalized flow volumes or amounts used to define a pattern for the flow disaggregation options. For defining a sub-monthly flow pattern, only the relative magnitude, not the actual magnitude, of the quantities is relevant.

APPENDIX B
INSTRUCTIONS FOR PREPARING *DAY* INPUT RECORDS

Flow disaggregation and routing parameter calibration jobs are specified in a program *DAY* input file with the filename extension DIN using the input records described in this appendix. The results are written to an output file with the filename extension DAY. The DAY file can be renamed with the DCF extension for use as a *DAY* or *SIMD* input file.

Program *DAY* reads monthly flows (*IN* records) and daily flows (*DF* records) from files with filename extensions FLO and DCF, respectively. The format of the *IN* records described in the *Users Manual* and the *DF* records described in the preceding Appendix A are the same for *DAY* and *SIMD*. Program *DAY* reads *IN* and *DF* records from the FLO and DCF files for only those control points specified in the *DIN* file. Records not needed are skipped. Program *DAY* can also read monthly and sub-monthly flows in columnar or row format from the FLO and DCF files.

Program *DAY* Input Records in a DIN File

** Record − Comments

field	columns	variable	format	value	description
1	1-2	CD	A2	**	Record identifier

Comment ** records are ignored by the computer program. Comment lines can be inserted between any records throughout the *DAY* input DIN file.

Records for Flow Disaggregation

JOBDIS Record − Monthly to Sub-Monthly (Daily) Flow Disaggregation Job

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	JOBDIS	Record identifier
					Number of Sub-Monthly Time Intervals in Output
2	9-16	NTI	I8	blank, 0	Default is number of calendar days in each month.
				+	Constant number of intervals in each month.
				−1	User defined time intervals per month to be given in the *NUMDAY* record.
					Method for Disaggregation
3	17-24	METH	I8	blank,0,1	Uniform distribution option.
				2	Linear interpolation option.
				3	Variability adjustment option.
				4	Flow pattern option.
				5	Drainage area ratio transfer option.
				6	Regression equation transfer option.
				−	Daily flows are read in columnar format and output in *DF* record format without disaggregation.
4	25-32	VOL	I8	blank,0	Monthly and daily input data for methods 5 and 6.
				1	Only daily input data is used for methods 5 and 6.
					Daily Flow Lag Option
5	33-40	LAG	I8	blank,0,+,−	Number of time steps to shift output daily pattern.
					Coefficients for METH Options 5 and 6
6	41-48	X	F8.0	+,blank,0	Option 5: Exponent, Default = 1.0 Option 6: Exponent, Default = 1.0
7	49-56	M	F8.0	+,blank,0	Option 5: Destination Area, Default = 1.0 Option 6: Multiplicative Coefficient, Default = 1.0
8	57-64	A	F8.0	+,blank,0	Option 5: Source Area, Default = 1.0 Option 6: Additive Coefficient, Default = 0.0
					Identifier and Formatting for Daily Flow Pattern
9	65-72	OUTFORM	I8	0	Columns of daily flows.
				1	Rows of daily flows.
				2	*SIMD DF* record formatted daily flows.
10	73-80	ID(J) J=I,N	2x,A6	AN	Identifier for the output daily flow pattern. N = 1 when METH > 0 N = ABS(METH) when METH < 0

A *JOBDIS* record results in generation of a sequence of flows with a daily or other sub-monthly time step at a single control point. Any number of flow disaggregation jobs may be included in a DIN file. For each job, the *JOBDIS* record is followed by the optional *NUMDAY* record and required *DFLOWS* records. The disaggregated flows are written to a DAY file and may be used for a subsequent *JOBMSK* record routing parameter calibration job.

Explanation of JOBDIS Record Fields

Field 2: Each of the 12 months may be divided into any number of intervals ranging from 1 to 32. The default is for the number of calendar days (28, 29 (leap year), 30, or 31) in each month to be assigned automatically. Leap years are considered automatically by assigning February 29 days instead of 28 days. Entering –1 in field 2 means that 12 integers that may vary between months are entered on a *NUMDAY* record.

Field 3: Disaggregation methods 1 through 6 are used to create a daily flow pattern from the data contained in the input file. Field 3 may be left blank if flows being simply read from the DCF file and written to the DAY file in a different format as specified in fields 9 and 10 without performing disaggregation. In this case, fields 4 through 8 of are ignored.

Field 4: Only monthly data is required in the input file if disaggregation method 1 or 2 is specified in field 3. Method 3 requires both monthly and daily input data. Method 4 requires only daily data. Methods 5 and 6 can use either a combination of monthly and daily input data or simply daily input data. This is equivalent to the use of variable *JTMETH* on the *JT* record. If monthly input volumes are used for methods 5 or 6, then the monthly input data controls the total volume and the daily input data is used as a pattern.

Field 5: *LAG* is used to shift the output daily flow pattern forward or backward a number of time steps. *LAG* > 0 would be used if the output corresponds to a location downstream of the input data. *LAG* < 0 would be used for shifting earlier in time, common for output corresponding to a location upstream of the input data.

Field 6-8: Disaggregation options 5 and 6 activated by field 3 are based on transferring a pattern established using flows from the source location in the input file to a destination location using one of the following equations with parameter values provided in fields 6–8.

$$P_{Destination} = \left[P_{Source} \left(\frac{Area_{Destination}}{Area_{Source}} \right) \right]^X$$

$$P_{Destination} = A + M \left(P_{Source} \right)^X$$

Field 9: The flows read directly or the disaggregated flows may be recorded in the DAY output file with filename extension DAY in three alternative formats. Alternatively, the flows may be used in a subsequent routing parameter calibration job without being written to the DAY file.

Field 10: The identifier *ID* is used to label the daily flow pattern recorded in the output file.

NUMDAY Record − Sub-Monthly Time Intervals in Output

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	NUMDAY	Record identifier
2-13	9-104	NDAY(I) I=1,12	12I8	+	Number of time steps in months 1 through 12.

Record *NUMDAY* is only used when *NTI* is equal to –1 on the *JOBDIS* record. The number of time steps *NDAY(I)* in each month can be set to any integer from 1 through 32.

DFLOWS Record − Disaggregation Flows Format and Time Range

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	DFLOWS	Record identifier
					Time Range to Use from the Input Data
2	9-16	MBEGYR	I8	+	First year for reading monthly data input.
3	17-24	MBEGMT	I8	+	First month for reading monthly data input.
				Blank	Default = 1
4	25-32	MENDYR	I8	+	Last year for reading monthly data input.
5	33-40	MENDMT	I8	+	Last month for reading monthly data input.
				blank	Default = 12
6	41-48	DBEGYR	I8	+	First year for reading daily data input.
7	49-56	DBEGMT	I8	+	First month for reading daily data input.
				blank	Default = 1
8	57-64	DENDYR	I8	+	Last year for reading daily data input.
9	65-72	DENDMT	I8	+	Last month for reading daily data input.
				Blank	Default = 12
					Formatting for the FLO and/or DCF Input File(s)
10	73-80	INFORM	I8	blank,0	Columns of flows (*METH* > 1)
				1	Rows of flows (*METH* > 1)
				2	Monthly flows in *SIM IN* record format; columnar daily flows if needed (*METH* > 1)
				3	Monthly flows in *SIM IN* record format; *SIMD DF* record format daily flows if needed (*METH* > 1)
				−1	Multiple columnar daily flow hydrograph. This format is only used when *METH* < 0.
11	81-88	CPIN	2x,A6	AN	Identifier of *IN* records in FLO file (*INFORM* = 2,3)
12	89-96	CPDF	2x,A6	AN	Identifier of *DF* records in DCF file (*INFORM* = 3)

Time Range for Reading Data from the Input File

The FLO and DCF input files containing monthly and daily flows can potentially cover a long period-of-record, of which the user may wish to work with only a subset. Using the *DFLOWS* record, a temporal range can be specified over which flow data is adopted for the disaggregation computations. For example, monthly flow data covering a period-of-record from 1900 through 2007 and daily flows for a few decades including the record drought occurring in the 1950's might be available. The user would be able to isolate the input data occurring in the worst year of the drought, say 1952, by selecting the appropriate starting and ending dates in fields 3 through 10 of the *DFLOWS* record.

If the disaggregation method selected does not require either monthly or daily input data, the corresponding fields on the *DFLOWS* record may be left blank. If the number of months for the daily input data is shorter than the selected period of record of the monthly input data, the daily data is repeated until the number of months in the monthly period-of-record is reached.

Columnar and Row Formatting for FLO and DCF Input Files When METH > 1

The columnar and row option for flow input is intended to accommodate the organization of flow time series with a spreadsheet. Formatted text with space delimited fields can be generated with spreadsheet programs such as Microsoft Excel.

Monthly columnar flows in the FLO file, *METH* > 1

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-10	MONTH	I4	+	Calendar month
3	11-14	(space)	4x	blank	
4	15-24	MFLOW	F10.0	+	Monthly flow

Monthly rows of flows in the FLO file, *METH* > 1

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-14	(space)	8x	blank	
3	15	MFLOWS(I) I = 1,12	12F10.0	+	Monthly flows

Daily columnar flows in the DCF file, *METH* > 1

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-10	MONTH	I4	+	Calendar month
3	11-14	DAY	I4	+	Calendar day
4	15-24	DFLOW	F10.0	+	Daily flow

Daily rows of flows in the DCF file, *METH* > 1

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-10	MONTH	I4	+	Calendar month
3	11-14	(space)	4x	blank	
3	15	DFLOWS(I) I = 1,NDAY	12F10.0	+	Daily flows

NDAY is equal to the calendar days per month or the value given on the *NUMDAY* record.

Daily columnar flows in the DCF file, *METH* < 0

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-10	MONTH	I4	+	Calendar month
3	11-14	DAY	I4	+	Calendar day
4	15-24	DFLOW(I) I = 1,Abs(*METH*)	F10.0	+	Daily flows

Records for Calibration of Routing Parameters

JOBRTG Record − Routing Parameter Calibration Job

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	JOBRTG	Record identifier
					Calibration Method
2	9-16	CALIB	I8	blank, 0, 1	Genetic optimization for all upstream gages.
				2	Simulation only to compute comparison statistics.
				3	Direct solution for Muskingum parameters.
					Genetic optimization for lag-attenuation parameters.
3	17-24	LAT	I8	blank, 0	No adjustments for lateral inflow volume.
				1	Adjustments for lateral inflow based on Eq. 3.15.
					Optimization Objective Function
4	25-32	FUNC	I8	blank, 0, 1	Objective function option 1 (Z_1) is applied.
				2	Objective function option 2 (Z_2) is applied.
				3	Objective function option 3 (Z_3) is applied.
				4	Objective function option 4 (Z_4) is applied.
				5	Objective function option 5 (Z_4) is applied.
					Weighting Factor for Objective Functions 4 and 5
5	33-40	WEIGHT	F8.0	blank, 0	Default weighting factor of 0.80 in Eq. 3.22 or 3.23
				+	Weighting factor (0.00 – 1.00) in Eq. 3.22 or 3.23
					Number and Names of Control Points
6	41-48	NGAGES	I8	+	Number of inflow(s) and outflow gages in calibration.
				blank, 0	Default = 2 for one inflow and one outflow gage.
7	49	GNAMES(I) I=1,NGAGES	2x,A6	AN	Names assigned to the inflow and outflow control points used in the calibration.

A calibration job controlled by a *JOBRTG* record consists of determining the lag and attenuation parameters for the lag-attenuation routing method or the K and X parameters for the Muskingum routing method for one, two, or more routing reaches ending at the same location. Routing parameters are often calibrated for a single reach defined by an upstream control point and a downstream control point. However, two or more tributaries may join at a common downstream confluence. Parameters for the multiple reaches flowing into the single downstream confluence site may be calibrated simultaneously as a single *JOBRTG* record job.

The *JOBRTG* record is followed by a set of *RTYPES*, *RLOWER*, *RUPPER*, *RFIXED*, *QLOWER*, and *QUPPER* records that provide information for each of the upstream control points defining the one or more reaches that share the same downstream control point. An *RFLOWS* record is also included in the set of calibration job input records in the DIN file to describe the input hydrograph data adopted from the DCF file. The *RFLOWS* record allows a specified temporal range of flows to be adopted for the calibration computations. Defaults are activated if any of these records that support the *JOBRTG* record are not included in the set.

Explanation of JOBRTG Record Fields

Either the lag-attenuation method or Muskingum method is adopted for each routing reach as specified by the *RTYPES* record for each of the one or more upstream control points. The default (no *RTYPES* record) is the lag-attenuation method. The routing parameters for the lag-attenuation method are the lag time and attenuation time, both in sub-monthly time steps (days). The routing parameters for the Muskingum method are K in time steps (days) and the dimensionless weighting factor X. With multiple reaches sharing a common downstream control point, the different reaches are not constrained to the same routing method.

Field 2: The optimization and iterative simulation calibration methods are applicable for both lag-attenuation and Muskingum parameters. Option 3 applies only to Muskingum routing. The default optimization option consists of automatically finding optimal parameter values within the program DAY based on a genetic search algorithm incorporating the objective function selected in field 4. Option 2 in field 2 consists of performing the routing computations with fixed user-specified values of the parameters entered on the *RFIXED* record. Program *DAY* provides comparison statistics and objective function values that summarize the comparison between computed flows and the given flows from the DCF file at the downstream control point.

Field 3: Net incremental local inflows are the differences in flow volume between the upstream and downstream control points defining a river reach. Reach outflows at the downstream control point are adjusted to remove incremental inflows based on Equation 3.15. Objective functions 3, 4, and 5 (field 4) may work better without adjustments for incremental inflows.

Field 4: The objective functions are defined by Equations 3.16, 3.17, 3.21, 3.22, and 3.23. The optimization computations performed by the genetic algorithm are based on minimizing the selected objective function. The optimization based on the objective function selected in field 4 is activated by option 1 in field 2. The simulation activated by option 2 in field 2 includes computation of values for all of the objective functions. Field 4 is relevant only if option 1 is selected in field 2, which includes a blank field 2 as well as a 0 or 1.

Field 5: The weighting factor W is defined by Equations 3.22 and 3.23.

Field 6: The input file must contain at least one inflow hydrograph and only one outflow hydrograph. Thus, there must be at least two control points defining the upstream and downstream ends of a routing reach. Multiple reaches sharing the same downstream control point are defined by multiple upstream control points. The total number of control points entered in field 6 includes the one downstream control point and all of the upstream control points. The following *RTYPES*, *RLOWER*, *RUPPER*, *RFIXED*, *QLOWER*, and *QUPPER* records provide information associated with each of the upstream control points.

Field 7: The entries for *GNAMES(I)* are optional unless the DCF file is in the format of *DF* records. If the *DF* record format is selected on the *RFLOWS* record, *GNAMES(I)* designates the *DF* records to read from the input file. If *GNAMES(I)* are not provided, *DAY* proceeds with the following default names where *N* is the total number of upstream (inflow) control points and *NGAGES* is N + 1 downstream (outflow) control point or stream flow gaging station.

GNAMES(1:*NGAGES*) = INFL_1, INFL_2, ... , INFL_*N-1*, OUTFLW

RTYPES Record − Type of Routing Method to Apply to the Upstream Flows

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	RTYPES	Record identifier
					Factor for Lag and Attenuation Calibration
2	9-16	LF	F8.0	blank,0.0	Default value of 0.25 is applied.
				+ to 1.0	Limit factor applied to calibration of attenuation.
					Type of Routing Method
3	17-24	RTYPE(I) I = 1, NGAGES – 1	A8	blank, L, LA	Lag and attenuation routing method is applied.
				M, MK	Muskingum routing method is applied.

Each of the *NGAGE* − 1 upstream control points (inflow gages) is assigned either the attenuation and lag routing method or Muskingum routing method. *NGAGE* is the total number of control points (stream flow gages) which includes one downstream gage plus any number of upstream gages. The default method is lag and attenuation. With no *RTYPES* record, the lag and attenuation method is adopted for all reaches.

Field 2: If the lag and attenuation method is selected for any of the *NGAGE* − 1 upstream control points with the *RTYPES* parameter, the value of field 2 is read. The value of field 2, *LF*, is ignored for any upstream control point assigned the Muskingum routing method. Additionally, the value of *LF* is ignored for any upstream control point assigned the lag and attenuation routing method that is also assigned a lower or upper limit on the value of attenuation via field 3 on the *RLOWER* or *RUPPER* record.

Attenuation can be defined as any real number between 1.0 and 1.0 plus the value of lag. However, the maximum theoretical value of attenuation, if allowed for consideration in the calibration process, may lead to a calibrated attenuation that distributes routed volumes over a large and unrealistic number of time steps at the downstream control point. Limiting the size of attenuation to a fraction of the value of lag plus 1.0 can improve the realism of the lag and attenuation parameters that are produced by the calibration. LF allows the calibration to vary the maximum valid size of attenuation as the calibration algorithm explores various sizes of lag. The dynamic resizing of the limit to attention is the difference between the application of *LF* and the *RLOWER* and *RUPPER* constraints. The value of *LF* may be specified as any positive real number less than or equal to 1.0. The default value of 0.25 is used if field 2 is zero or blank.

The following calibration range is set for any upstream control point using the lag and attenuation routing method that does not also have a specific minimum or maximum constraint applied to attenuation by the RLOWER or RUPPER records:

$$\text{Attenuation} \geq 1.0$$
$$\text{Attenuation} \leq 1.0 + LF \times \text{Lag}$$

RLOWER Record − Lower Boundary for Routing Parameters in the Optimization

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	RLOWER	Record identifier
2	16	RPARAM	I8	blank, 0 1, +	This record applies to lag or Muskingum K. This record applies to attenuation or Muskingum X.
3	24	RMIN(I) I = 1, NGAGES – 1	F8.3	0.0, + −1	Lower limit or minimum value of parameter. Default limits are applied.

RUPPER Record − Upper Boundary for Routing Parameters in the Optimization

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	RUPPER	Record identifier
2	16	RPARAM	I8	blank, 0 1, +	This record applies to lag or Muskingum K. This record applies to attenuation or Muskingum X.
3	24	RMAX(I) I = 1, NGAGES – 1	F8.3	0.0, + −1	Upper limit or maximum value of parameter. Default limits are applied.

The optional *RLOWER* and *RUPPER* records are applicable only for the optimization option set by the default first option in *JOBRTG* record field 2. Upper and lower limits are placed on the parameter values in the automatic search for parameter values that minimize the objective function selected in *JOBRTG* record field 4. If the *RLOWER* and *RUPPER* records are omitted or a value of −1 is entered on either the *RLOWER* or *RUPPER* record for one or more of the reaches, the optimization is performed with the following default constraints.

For lag-attenuation routing: $0.0 \leq LAG \leq 19.0$ $1.0 \leq ATT \leq 20.0$

For Muskingum routing: $0.5 \leq K \leq 10.0$ $0.0 \leq X \leq 0.5$

RFIXED Record − Fixed Value for Routing Parameters

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	RFIXED	Record identifier
2	16	RPARAM	I8	blank, 0 1, +	This record applies to lag or Muskingum K. This record applies to attenuation or Muskingum X.
3	24	RFIX(I) I = 1, NGAGES − 1	F8.3	0.0, + −1	Fixed values of the routing parameter. No fixed parameter value is applied.

RLOWER, *RUPPER*, and *RFIXED* records apply to the single parameter specified in field 2 which varies between lag-attenuation routing (lag or attenuation) and Muskingum (K or X).

A *RFIXED* record is required, with positive or zero values for the routing parameters for all upstream gages, when calibration option 2 is selected for *CALIB* in *JOBRTG* record field 2.

The *RFIXED* record is optional for the optimization-based calibration option activated by 0 or 1 in *JOBRTG* record field 2. Positive values for one or more parameters entered on a *RFIXED* record will replace any positive values specified on the *RLOWER* or *RUPPER* records. The optimization may not reach the global optimum in the parameter space if one or more routing parameters are fixed with a *RFIXED* record. Generally, it is best to allow the defaults constraints to apply or define sufficiently wide margins with *RLOWER* and *RUPPER* for the optimization.

With the iterative simulation approach to calibration, *DAY* performs the routing with the parameters entered on the *RFIXED* record and creates a table of statistics and criteria functions comparing the computed flows at the downstream control point with the corresponding known flows read from the DCF file. The user reruns *DAY* with alternative values for the parameters in a trial-and-error search for optimal parameter values. Another calibration strategy is to first run DAY in optimization mode to obtain an initial set of parameter values which can then be further refined by iterative trial-and-error simulations using the *RFIXED* record.

RFLOWS Record − Time and Formatting of the Input Flow Hydrographs

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	RFLOWS	Record identifier
					Temporal Range
2	9-16	BEGYR	I8	+	First year for reading input hydrographs.
3	17-24	BEGMT	I8	blank, +	First month reading input hydrographs. Default = 1
4	25-32	ENDYR	I8	+	Last year for reading input hydrographs.
5	33-40	ENDMT	I8	blank, +	Last month reading input hydrographs. Default = 12
					Format of Input File
6	41-48	INFORM	I8	blank, 0	Daily flows in columnar format
				1	Daily flows (calendar days) in *DF* record format

The *RFLOWS*, *QLOWER*, and *QUPPER* records control the selection of flow ranges in the use of flows from the DCF file in the calibration computations. Options controlled by these records are discussed on this page and the next page.

The switch variable *INFORM* in *RFLOWS* record field 6 indicates whether the flows in the DCF file are in the format of *DC* records or the columnar format outlined below. Any number of comment ** records may appear as a header in the DCF file.

Optional Columnar Format for Sub-Monthly (Daily) Flows in the DCF File

field	columns	variable	format	value	description
1	1-6	YEAR	I6	+	Calendar year
2	7-10	MONTH	I4	+	Calendar month
3	11-14	DAY	I4	+	Calendar day
4	15	INFLOW(I) I = 1, NGAGES − 1	F10.0	+	Daily flows at upstream (inflow) control points (gages).
		OUTFLOW	F10.0	+	Daily flow at the outflow gage.

QLOWER Record − Lower Constraints for Upstream Flow in the Optimization

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	QLOWER	Record identifier
2	9-16		8x		Field is not used.
3	17-24, ...	QMIN(I) I = 1, NGAGES − 1	F8.0	+ blank, 0	Lower limit on upstream flows used in optimization. Default = 0.0

QUPPER Record − Upper Constraints for Upstream Flow in the Optimization

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	QUPPER	Record identifier
2	9-16		8x		Field is not used.
3	17-24, ...	QMAX(I) I= 1, NGAGES − 1	F8.0	+ blank, 0	Upper limit on upstream flows used in optimization. Default = no upper limit

The DCF file contains flows at the upstream and downstream control point locations of the inflow and outflow hydrographs for each routing reach. Inflow hydrographs are provided for each of the *NGAGE* − 1 upstream control points (inflow gages) *NGAGE* is the total number of control points (stream flow gages) which includes one downstream gage plus any number of upstream gages. The inflows considered in the parameter calibration computations may be limited to only those flows falling within the range defined by the upper and lower limits specified on *QUPPER* and *QLOWER* records.

Discussion of the Time Periods and Flow Ranges Defined by *RFLOWS*, *QLOWER*, and *QUPPER* Records

The flow hydrographs in the DCF input file may cover a long period-of-record. The entire period-of-record can be considered in calibrating the routing parameters. Alternatively, a subset of the period-of-record, ranging from a single month up to the entire period-of-record, can be selected for the calibration. Subsets of flows can also be defined by specifying minimum and/or maximum flow limits. Parameters for routing flow changes associated with flood control operations may be set separately from parameters for routing other flow changes. In addition to differentiating between flood flows and normal flows, various ranges of low to high flows may be of interest for other reasons as well in calibration studies.

The *RFLOWS*, *QLOWER*, and *QUPPER* records provide options for selecting ranges of flows for use in the calibration computations. These are ranges of the inflows at upstream control points. All flows for the entire period-of-record are included in the routing computations performed by *DAY*. However, only the selected subset of flows is included in the computation of the objective function to be minimized in the optimization algorithm based automated calibration routine. Also, only the selected subset of flows is included in the comparison statistics computed by *DAY* for use in the iterative simulation calibration strategy.

Flows might be provided in a DCF file, for example, for a period-of-record extending from 1940 to 2007. The flow regime during this long period-of-record might range from periods of severe multiple-year drought to major floods. The *RFLOWS* record can be used to isolate the one or more months containing a major flood event. A time period is specified on a *RFLOWS* record. Alternatively, minimum or maximum flow limits *QMIN(cp)* and *QMAX(cp)* may be specified on *QLOWER* and *QUPPER* records. A flow range can be set so that only time steps (days) with flows above a certain level (for example *QMIN(cp)* = 12,500 cfs) at the upstream control point are considered. All days are used in the lag-attenuation or Muskingum routing computations performed by *DAY* but only the days with mean daily inflows exceeds 12,500 cfs are used by *DAY* to compute the values for the objective function defined in *JOBRTG* record field 4.

The calibration of routing parameters with a *JOBRTG* record and set of supporting *DAY* input records allows for multiple upstream upstream gages (control points). Different values of *QMIN(cp)* and *QMAX(cp)* can be selected for application to each individual upstream gage. However, if values of *QMIN(cp)* and/or *QMAX(cp)* are assigned for one upstream gage but not the others, the same subset of days defined by the gage with the *QMIN(cp)* and/or *QMAX(cp)* assignment will be applied to all of the reaches. For example, there may be three upstream gages in a calibration job, but flood flows are defined by *QMIN(cp)* on a *QLOWER* record for just one of the upstream gages. The optimization will proceed to find the optimal routing parameter value for each of the three reaches using the same subset of daily flows defined by the single *QMIN(cp)*.

CHECKS Record − Optional Data for DMS File Output

field	columns	variable	format	value	description
1	1-8	CD	A6,2x	CHECKS	Record identifier
2	16	C1	I8	blank, 0	No data written
				+	Statistics of gaged flow input data
3	24	C2	I8	blank, 0	No data written
				+	Routed hydrograph time series

Explanation of CHECKS Record Fields

Field 2: The following statistics for the monthly aggregated input gaged flow data are written to the DMS file for a positive value in field 2:

- Days per month within the QLOWER and QUPPER flow range
- Average monthly upstream gaged flow
- Peak daily flow per month
- Percentage of gaged upstream flow to the gaged downstream flow per month
- Average monthly downstream gaged flow

Field 3: The time series of upstream and downstream gaged flows and the routed hydrograph are written to the DMS file. The routing parameters used to generate the routed hydrograph from the gaged upstream flows are also written to the DMS file.

APPENDIX C
INSTRUCTIONS FOR PREPARING *TABLES* INPUT RECORDS

Instructions for applying program *TABLES* provided in Chapter 4 of the *Users Manual* are supplemented as follows to cover conditional reliability modeling, sub-monthly time step, and flood control features of the expanded WRAP. *TABLES* features related to salinity are covered in the *Salinity Manual*. The *TABLES* input record types included in Appendix C are listed in the following table. *TABLES* input records are entered in a file with the filename extension TIN. These input records provide specifications for creating tables and data listings that organize the simulation results read by *TABLES* from *SIM* and *SIMD* output files.

TABLES Input Records Described in Appendix C

Type 6 Tables Based on a Sub-Monthly Time-Step

The *2REL*, *2FRE*, *2FRQ*, and *2RES* records used with monthly simulation results are described in Chapter 4 of the *Users Manual*. The type 2 monthly records are used with a *SIM* or *SIMD* conditional reliability modeling output file with filename extension CRM if and only if preceded by a *5CRM* or *5CR2* record. Otherwise, the type 2 frequency and reliability records, type 2 time series records, and other type 2 records are used with a *SIM* or *SIMD* output OUT file. The sub-monthly *6REL*, *6FRE*, *6FRQ*, and *6RES* records and type 6 time series records are used with a *SIMD* sub-monthly file with filename extension SUB.

The fields of the type 6 sub-monthly *6REL*, *6FRE*, *6FRQ*, and *6RES* records are identical to the corresponding type 2 monthly *2REL*, *2FRE*, 2*FRQ*, and *2RES* records described in the *Users Manual*. The type 2 and type 6 time series records are also the same. The IDEN record is also used the same. The tables defining the fields for the *6REL*, *6FRE*, *6FRQ*, and *6RES* records and type 6 time series records are reproduced here. The additional explanations for each field found in the *Users Manual* for the type 2 (monthly time interval) records also apply to the corresponding type 6 sub-monthly time step records and are not reproduced here. The frequency and reliability analyses computations performed within *TABLES* and the format of the resulting tables in the TOU file are basically the same for type 2 and type 6 records. The tables created with type 6 records include an additional line in the table heading indicating the time step and period-of-analysis used in the simulation.

IDEN Records – Identifiers of Control Points, Water Rights, Water Right Groups, or Reservoirs

field	columns	variable	format	value	description
1	1-4	CD	A4	IDEN	Record identifier
2-9	5-68	IDCP(I) IDRES(I) IDEN8(I)	8(2x,A6) 8(2x,A6) 8A8	AN	Identifiers of control points (ID=TID=0), reservoirs (ID=TID=2), water rights (ID=TID=1), water right groups (ID=TID =3). Used for positive NUM=NID.
	5-132	IDEN16(I) I = 1, NUM	8A16		Eight identifiers per record on up to ten records for a total of up to 80 identifiers.

IDEN records are used in association with various type 2 and type 6 records to list identifiers of control points, reservoirs, water rights, and water right groups. A positive entry for *NUM* on a 6REL, 6FRE, 6FRQ, 6RES record, type 6 time series record, or equivalent type 2 record indicates that *NUM* identifiers are to be read from one or more IDEN records.

6REL Record – Water Supply Diversion or Hydroelectric Energy Reliability Summary

field	Columns	variable	format	value	description
1	1-4	CD	A4	6REL	Record identifier
2	7-8	MON	I4	blank,0	All months are included in the computations.
				+	The month for which the analysis is performed.
3	12	RFLAG	I4	blank,0	N = number of months with non-zero targets
				1,+	N = (years)(12 months/year) for $R_P = (n/N) \times 100\%$
4	16	ID	I4	0	Table includes selected control points.
				1	Table includes selected water rights.
				2	Table includes selected hydropower reservoirs.
				3	Table includes selected water right groups.
5	19-20	NUM	I4	blank,0	Include all control points (ID=0), water rights (ID=1), or reservoirs (ID=2) in table.
				+	Number of water rights, reservoirs, water right groups, or control points to follow on IDEN record(s).
				–	NUM identifiers from previous record are repeated.
6	21-28	TAR	F8.0	blank,0	Optional supplemental table is not created.
				+	Annual diversion or hydropower target.
				−1, −	Adopt total of targets from *SIM* output file.
7	32	VUL	I4	≥1	Optional vulnerability and resiliency table is created.

The 6REL and 2REL records have the same entries. Explanations of the 2REL record fields in the *Users Manual* also apply to the 6REL record. The 2REL record creates a reliability table with volume reliabilities, period reliabilities based on monthly targets and shortages, and period reliabilities based on annual targets and shortages. The 6REL reliability table has an additional section with period reliabilities based on sub-monthly (such as daily) targets and shortages.

A 6REL record reads sub-monthly *SIMD* simulation results from a SUB file. A 2REL record reads monthly simulation results from an OUT file created by either *SIM* or *SIMD*. Results from a *SIMD* simulation using a daily or other sub-monthly time step may be aggregated to monthly values which are recorded in the OUT file.

The values of volume reliabilities will the same on the 2REL and 6REL tables developed from OUT and SUB files generated by the same *SIMD* simulation, but period reliabilities will differ. The values of period reliabilities vary between daily, monthly, and annual time steps. Volume reliability is the total water volume supplied (or hydroelectric energy generated) as a percentage of total demand (target) without reference to time step.

The parameters *ND* and *SHORT* in *SIMD* input *DW* record fields 5 and 6 activate an optional feature described in Chapter 3 in which shortages incurred early in a month may be recovered later during the month. Shortages are recorded in the SUB file even though supplied later in the month. Thus, the 6REL record sub-monthly based reliabilities are ***not*** valid for water rights for which the *ND/SHORT* feature is applied in *SIMD*. However, reliabilities based on aggregated monthly simulation results are valid. The aggregated monthly targets and shortages are correct.

6FRE Record – Flow-Frequency or Storage-Frequency Relationships

field	columns	variable	format	value	description
1	1-4	CD	A4	6FRE	Record identifier
2	7-8	Variable	I4	1	Naturalized flows (ID=0)
				2	Regulated flows (ID=0)
				3	Unappropriated flows (ID=0)
				4	Reservoir storage associated with control point (ID=0)
				–4	Reservoir storage associated with a control point with only totals included in table (ID=0)
				5	Reservoir storage associated with a water right (ID=1)
				–5	Reservoir storage associated with a water right with only totals included in table (ID=1)
				6	Reservoir storage associated with a reservoir (ID=2)
				−6	Reservoir storage associated with a reservoir with only totals included in table (ID=2)
				7	Reservoir water surface elevation (ID=2)
				8	Instream flow shortage for an *IF* record right (ID=1)
				9	Instream flow shortage at a control point (ID=0)
				10	DATA record daily array.
				11	DATA record annual array.
3	11-12	MON	I4	blank, 0	All months are included in the computations.
				+	The month for which the analysis is performed.
4	15-16	NUM	I4	0	Include all control points, rights, or reservoirs in table.
				+	Number of control points, rights, or reservoirs.
				–	NUM identifiers from previous record(s) are repeated.
5	20	TABLE	I4	blank, 0, 1	Frequency table is created in standard row format.
				2	Frequency results are tabulated as columns.
				3	Abbreviated frequency results tabulated as columns.
				4	Quantities are expressed as a percentage of maximum.
6	24	METHOD	I4	blank, 0, 1	Relative frequency $P = (n/N)\ 100\%$
				2	Log-normal probability distribution.
				3	Normal probability distribution.
7	28	MAT	I4	blank, 0	Moving average/total option is not adopted.
				1	Moving averages are computed for TIME months.
				2	Moving totals are computed for TIME months.
8	32	TIME	I4	+	Number of months for moving averages or totals.
9	33-40	XF	F8.0	+, −, blank	Multiplier factor. Default multiplier factor = 1.0
10	41-48	AF	F8.0	+, −, blank	Addition factor. Default addition factor = 0.0

The 6FRE and 2FRE records have the same format and produce tables with the same format. Explanations of the 2FRE record fields in Chapter 4 of the *Users Manual* also apply to the 6FRE record. The tables created with a 6FRE record or any other type 6 record include an additional line in the table heading indicating the time step and period-of-analysis used in the simulation.

6FRQ Record – Frequency for Specified Flow or Storage

field	columns	variable	format	value	description
1	1-4	CD	A4	6FRQ	Record identifier
2	8	Variable	I4	1 2 3	Naturalized flows (ID=0) Regulated flows(ID=0) Unappropriated flows (ID=0)
				4 5 6	Reservoir storage associated with a control point(ID=0) Reservoir storage associated with a water right (ID=1) Reservoir storage associated with a reservoir (ID=2)
				7	Reservoir water surface elevation (ID=2)
				8 9	Instream flow shortage for an *IF* record right (ID=1) Instream flow shortage at a control point (ID=0)
				10 11	DATA record monthly or daily array DATA record annual array (pages 143-145)
3	12	MONTH	I4	0,blank +	All months are included in the computations. The month for which the analysis is performed.
4	16	NM	I4	+	Number of flows or storages entered for *TABLES* to determine frequencies (NM may range from 1 to 7)
5	17-24 17-32	IDEN IDEN16	2x,A6 A16	AN	Identifier of control point (field 2 variables 1-4), water water right (variables 5, 8), or reservoir (variables 6, 7)
6-12	25-80 33-88	QF(I) I=1,NM	7F8.0	+	Streamflow (variables 1,2,3), storage (variables 4,5,6), elevation (7), or instream flow shortage (variables 8,9)

The 6FRQ and 2FRQ records have the same input entries and produce tables with identically the same format, though the values of the variables recorded in the tables will vary. Explanations of the 2FRQ record fields in the *Users Manual* also apply to the 6FRQ record. The tables created with a 6FRQ record or any other type 6 record include an additional line in the table heading indicating the time step and period-of-analysis used in the simulation.

6RES Records – Reservoir Storage Tables

First 6RES Record

field	Columns	variable	format	Value	Description
1	1-4	CD	A4	6RES	Record identifier
2	8	TABLE	I4	0	All three tables are created.
				1	Storage contents as a percentage of capacity table.
				2	Storage draw-down duration table is created.
				3	Storage reliability table is created.
				4	Both draw-down and reliability tables are created.
3	11-12	MONTH	I4	0,blank	All months are included in the computations.
				+	The month for which the analysis is performed.
4	15-16	NUM	I4	+	Number of reservoir identifiers in following fields.
5-24	17-176	IDEN(res) res=1,20	20(2x,A6)	AN	Reservoir identifiers

Second 6RES Record – Total Storage Capacity (required)

field	columns	variable	format	Value	Description
1	1-4	CD	A4	6RES	Record identifier
2-4	5-16		12X		Blank or comments (not read by *TABLES*)
5-24	17-176	C1(res) res=1,20	20F8.0	+	Total storage capacity in each reservoir (C_1).

Third 6RES Record – Inactive Storage Capacity (optional)

field	columns	variable	format	Value	Description
1	1-4	CD	A4	6RES	Record identifier
2-3	5-16		12X		Blank or comments (not read by *TABLES*)
5-24	17-176	C2(res) res=1,20	20F8.0	+	Inactive storage capacity in each reservoir or bottom of the storage zone being considered (C_2).

The third 6RES record is generally optional, with all C_2 defaulting to zero. However, the third record is required even if the C_2 are zero if followed by another set of 6RES records.

The detailed explanations of the type 2 monthly versions of these records found in the *Users Manual* are also applicable to the type 6 sub-monthly time step versions.

Sub-Monthly Time-Step Time Series

As discussed in Chapter 4 of the *Users Manual*, the time series input records build tables in the same optional formats, with the only difference being the selection of variable from the list below to be tabulated. The items in parenthesis indicate whether the variable is associated with a control point, water right, and/or reservoir. The monthly (type 2) and sub-month (type 6) versions of the time series records obtain simulation results from OUT and SUB files, respectively.

6NAT Record – Naturalized Stream Flow (control points)
6REG Record – Regulated Stream Flow (control points)
6UNA Record – Unappropriated Stream Flow (control points)
6CLO Record – Channel Loss (control points)
6CLC Record – Channel Loss Credits (control points)
6RFR Record – Return Flow Entering at this Control Point (control points)
6URR Record – Upstream Reservoir Releases (control points)
6CPI Record – Control Point Inflows excluding Secondary Reservoir Releases (control points)
6STO Record – Reservoir Storage (control points, water rights, reservoirs)
6EVA Record – Reservoir Evaporation-Precipitation Volume (cpts, water rights, reservoirs)
6DEP Record – Stream Flow Depletion (control points, water rights)
6TAR Record – Diversion Target (control points, water rights)
6SHT Record – Diversion Shortage (control points, water rights)
6DIV Record – Diversion (control points, water rights)
6RFL Record – Return Flow (water rights)
6XAV Record – Increase in Available Stream Flow (water rights)
6ASF Record – Available Stream Flow (water rights)
6ROR Record – Releases from Other Reservoirs (water rights)
6IFT Record – Instream Flow Target (instream flow rights, control points)
6IFS Record – Instream Flow Shortage (instream flow rights, control points)
6FSV Record – Flow Switch Volume (instream flow rights)
6FSC Record – Flow Switch Count (instream flow rights)
6HPS Record – Hydropower Shortage (+) or Secondary Energy (–) (reservoir/hydropower)
6HPE Record – Energy Generated (reservoir/hydropower)
6RID Record – Inflows to Reservoir from Stream Flow Depletions (reservoir/hydropower)
6RIR Record – Inflows from Releases from Other Reservoirs (reservoir/hydropower)
6RAH Record – Releases Accessible to Hydropower (reservoir/hydropower)
6RNA Record – Releases Not Accessible to Hydropower (reservoir/hydropower)
6EPD Record – Adjusted Evaporation-Precipitation Depths (reservoir/hydropower)
6EVR Record – Evaporation-Precipitation Depths from *EV* Records (reservoir/hydropower)
6WSE Record – Reservoir Water Surface Elevation (reservoir/hydropower)
6RSC Record – Reservoir Storage Capacity (reservoir/hydropower)
6RSD Record – Reservoir Storage Drawdown (reservoir/hydropower)

Time Series Records – All Record Types Listed on Preceding Page

field	columns	variable	format	value	description
1	1-4	CD	A4	page 260 6DAT	Record identifier from the list on the preceding page or 6DAT to connect to a DATA record.
2	5-8		4x		Field not used with 6SUB record submonthly interval.
3	12	PT	I4	blank,0 1 2 3 4 5	Do not activate either HEC-DSS or text file option. Columns of sub-monthly (daily) data in text file. Develop columns of annual totals or means in text file. Develop columns of 12 monthly means in text file. HEC-DSS sub-monthly (daily) time series records. Develop HEC-DSS annual time series records.
4	16	MORE	I4	0 1	Write columns; next record starts a new table. Add more columns to existing table or start first table.
5	20	ID	I4	0 1 2 3	Develop tables for default ID or for control points. Develop tables for water rights. Develop tables for reservoirs. Develop tables for water right groups.
6	24	NUM	I4	blank,0 − +	Tables for all control points (ID=0), rights (ID=1), or reservoirs (ID=2). NUM cannot be zero if ID=3. Develop tables for the NUM control points, water rights, or reservoirs listed on a previous record. Number of control points, water rights, reservoirs, or water right groups to follow on IDEN records.
7	28	DECIMAL	3x,A1	blank 0,1,2,3,4	Standard number of digits. Number of digits to the right of the decimal.
8	32	MAT	I4	blank,0 1 2	Moving average/total option is not adopted. Moving averages are computed for TIME days. Moving totals are computed for TIME days.
9	33-36	TIME	I4	+	Number of days for moving averages or totals.
10	37-44	XF	F8.0	+, −, blank	Multiplier factor. Default multiplier factor = 1.0
11	45-52	AF	F8.0	+, −, blank	Addition factor. Default addition factor = 0.0

TABLES type 6 time series record routines read *SIMD* simulation results from a SUB file and write the data in the following formats as specified by field 3.

- a text file with filename extension TOU with each time series variable tabulated as one column of a table
- a binary file with filename extension DSS with each time series variable stored as a HEC-DSS record

Flood Frequency and Damage Analyses

7FFA Record – Flood Frequency Analysis

field	columns	variable	format	value	Description
1	1-4	CD	A4	7FFA	Record identifier
2	5-8	ID	I4	blank,0,1	Naturalized flows
				2	Regulated flows
				3	Reservoir storage
				4	Summation of reservoir storage and excess flow
3	12	TAB	I4	blank,0,1	Annual frequency table based on log-Pearson III.
				2	Both frequency table and statistics table.
				3	Frequency and economic damage table.
				4	Both frequency/damage table and statistics table.
				−1	Table is not created.
4	16	RANK	I4	blank,0,−1	Ranked tabulation is not included in output.
				1,+	Ranked annual peaks with Weibull probabilities.
5	20	NUM	I4	blank,0	Tables for all control points included in AFF file.
				+	Number of control point identifiers on IDEN records.
6	23-24	SKEW	I4	Blank,0,1	Skew coefficients are computed.
				2	Skew coefficients are provided on SKEW record(s).
				3	Weighted skew coefficient combining 1 and 2 above.
				4	Skew coefficient provided in field 7.
				5	Weighted skew coefficient combining 1 and 4 above.
				6	Skew coefficients are all zero.
7	25-32	SC1	F8.0	+ or −	Single skew coefficient for all control points.

IDEN Records – Control Point Identifiers for a 7FFA Record

field	columns	variable	format	value	description
1	1-4	CD	A4	IDEN	Record identifier
2-9	5-68	IDCP(I)	8(2x,A6)	AN	Identifiers of control points (up to 80, eight per record)

SKEW Record – Skew Coefficients for a 7FFA Record

field	columns	variable	format	value	description
1	1-4	CD	A4	SKEW	Record identifier
2-13	5-132	SC(I)	8F8.0	+ or −	Skew coefficients (up to 8 per record)

7VOL Record – Flow or Storage Volume Causing Damages on Following 7DAM Record

field	columns	variable	format	value	description
1	1-4	CD	A4	DVOL	Record identifier
2	5-12	CPID	2x,A6	AN	Control point identifier.
3	15-16	N	I4	+	Number of values to read (1 to 20).
4-23	17-176	DV(I) I=1,20	20F8.0	+	Flow or storage volume corresponding to $ damage on the following 7DAM record (up to 20 pairs).

7DAM Record – Damage Corresponding to Quantities on Preceding 7VOL Record

field	columns	variable	format	value	description
1	1-4	CD	A4	$DAM	Record identifier
2	5-12		8x		Field is not read.
3	13-16		4x		Field is not read.
4-23	17-176	DAM(I) I=1,20	20F8.0	+	Flood damage in $ corresponding to stream flow or reservoir storage volume on preceding 7VOL record.

Flood frequency analysis capabilities and the associated damage analysis option are covered in Chapter 5. These *TABLES* analyses use data from a *SIMD* annual flood frequency AFF file.

The *7FFA* record activates a routine which applies the log-Pearson probability distribution to the annual series of maximum naturalized flow, regulated flow, or reservoir storage read from an AFF file created by *SIMD* to develop an annual frequency table. The *RANK* parameter in 7FFA record field 4 also creates a table assigning an exceedance frequency computed with the Weibull formula to each peak annual flow or storage volume.

A set of *7VOL* and *7DAM* records expands the frequency table to include economic flood damages. Annual damages in dollars corresponding to each exceedance frequency and average annual damages are included in the table.

The *7FFA* record may be applied without the optional *IDEN*, *SKEW*, *7VOL*, and *7DAM* records. An *IDEN* record is required if and only if activated by NUM in *7FFA* field 5. A *SKEW* record is required if and only if activated by *SKEW* in *7FFA* field 6. Without *7VOL* and *7DAM* records, the frequency table includes only naturalized or regulated flow or storage volumes. With *7VOL* and *7DAM* records inserted, the frequency table is expanded to include dollar damages.

IDEN records, if used, must follow immediately after the *7FFA* record. *SKEW* records, if used, must follow behind the *7FFA/IDEN* records. The set of all pairs of *7VOL* and *7DAM* records follow the *7FFA*, *IDEN*, and *SKEW* records. A *7DAM* record follows immediately after the corresponding *7VOL* record.