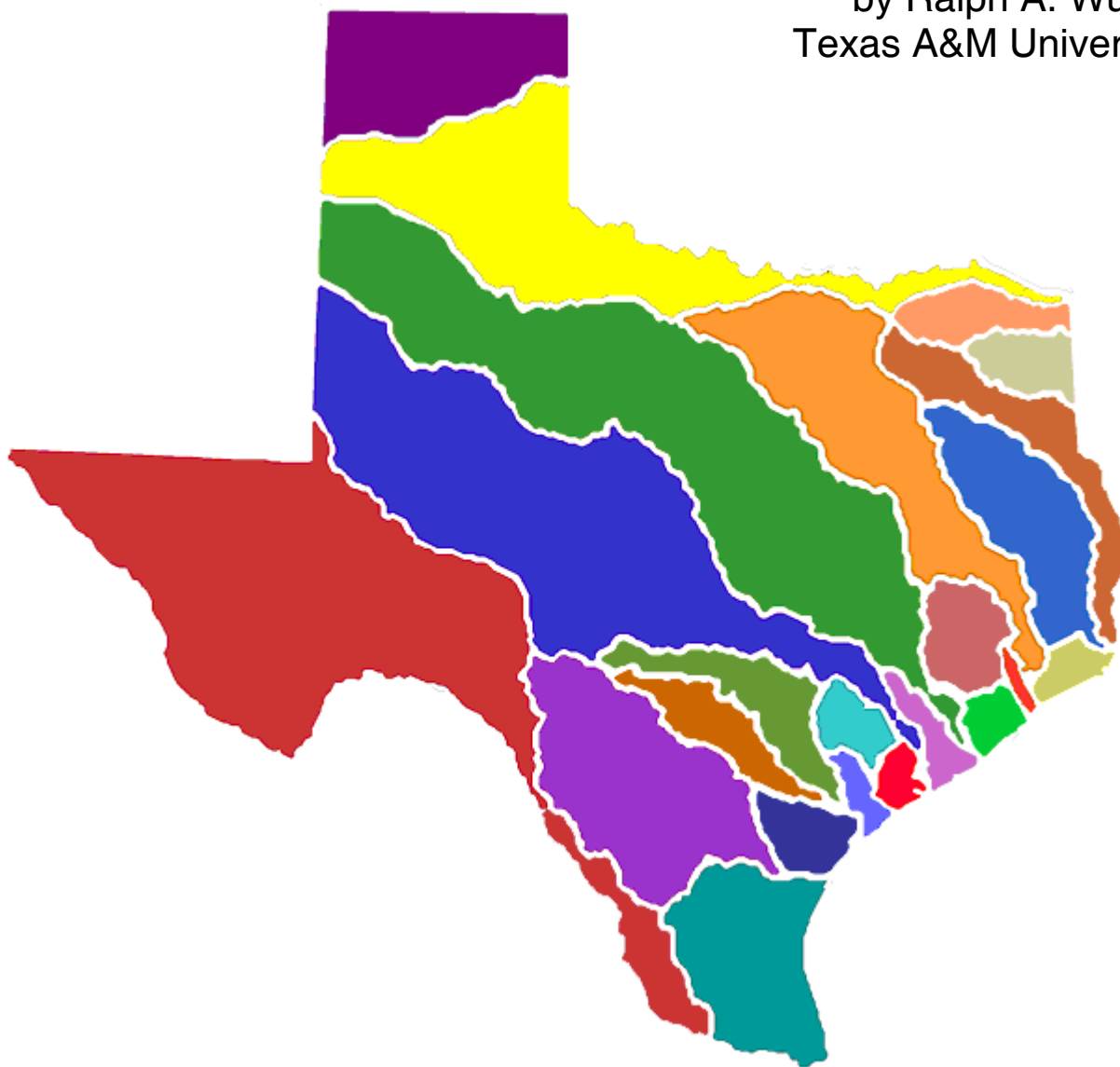


# Water Rights Analysis Package (WRAP) Modeling System Reference Manual

by Ralph A. Wurbs  
Texas A&M University



TR-255  
Texas Water Resources Institute  
College Station, Texas  
March 2008



# **Water Rights Analysis Package (WRAP) Modeling System Reference Manual**

by

Ralph A. Wurbs  
Department of Civil Engineering and  
Texas Water Resources Institute  
Texas A&M University

for the

Texas Commission on Environmental Quality  
Austin, Texas 78711-3087

under

TCEQ/TWRI Contract 9880074800 (1997-2003)  
TCEQ/TEES Contract 582-6-77422 (2005-2008)

Cosponsored with Supplemental Funding Support

from the

Texas Water Development Board  
Fort Worth District, U.S. Army Corps of Engineers  
Texas Water Resources Institute, Texas A&M University System

Technical Report No. 255  
Texas Water Resources Institute  
The Texas A&M University System  
College Station, Texas 77843-2118

First Edition, August 2003  
Second Edition, April 2005  
Third Edition, September 2006  
Fourth Edition, March 2008



## TABLE OF CONTENTS

<b>Acknowledgements</b> .....	vii
<b>Chapter 1 Introduction</b> .....	1
WRAP Documentation .....	1
WRAP Programs .....	3
Auxiliary Software .....	5
Texas WAM System .....	7
Model Development Background .....	11
Organization of the Reference and Users Manuals .....	14
<b>Chapter 2 Overview of the Simulation Model</b> .....	15
Modeling Capabilities .....	15
Water Availability Modeling Process .....	16
Long-Term, Yield-Reliability, and Conditional Reliability Modeling Modes .....	17
Control Point Representation of Spatial Configuration .....	18
Simulation Input .....	19
Simulation Results .....	20
Units of Measure .....	21
Organization of the Simulation Computations .....	22
Constructing a Model with WRAP .....	30
Measures of Water Availability and Reliability .....	38
Program SIM Options Involving Cyclic Repetitions of the Simulation .....	41
<b>Chapter 3 Hydrology Features</b> .....	43
Naturalized Stream Flow .....	44
Reservoir Evaporation-Precipitation .....	46
Program HYD Hydrology Data Manipulation Capabilities .....	47
HYD Features for Developing Evaporation-Precipitation Datasets .....	50
Regression Equation to Adjust Flows and/or Evaporation-Precipitation Depths .....	50
HYD Features for Developing Stream Flow Datasets .....	51
Allocation of Stream Flow within SIM .....	55
Channel Losses .....	56
Methods for Establishing Stream Flow Inflows .....	60
Distribution of Naturalized Flows from Gaged to Ungaged Control Points .....	61
Use of GIS to Determine Spatial Connectivity and Watershed Parameters .....	73
Negative Incremental Naturalized Stream Flows .....	74
<b>Chapter 4 Water Management Features</b> .....	89
Water Rights .....	89
Water Right Priorities .....	91
Water Availability within the Priority-Based Water Rights Computation Loop .....	93
Specifying Targets and Rules for Meeting the Targets .....	94
Setting Diversion, Instream Flow, and Hydropower Targets .....	96
River/Reservoir System Operating Rules for Meeting Water Use Requirements .....	102
Reservoir Storage .....	107
Multiple-Reservoir and Multiple-Right Reservoir Systems .....	110

## TABLE OF CONTENTS (Continued)

Multiple Reservoir System Operations .....	112
Iterative Reservoir Volume Balance Computations .....	116
Multiple Rights Associated with the Same Reservoir .....	117
Water Supply Diversions.....	123
Return Flows .....	123
Other Inflows and Outflows .....	125
Hydroelectric Energy Generation .....	126
Instream Flow Requirements .....	131
Dual Simulation Options .....	140
Options for Circumventing the Priority Sequence .....	142
<b>Chapter 5 Organization and Analysis of Simulation Results .....</b>	<b>151</b>
OUT, SOU, and DSS Files .....	151
SIM Simulation Results Variables .....	153
Organization of SIM OUT Output File .....	158
Types of TABLES Tabulations .....	165
Time Series Tables and Tabulations .....	167
Reliability and Frequency Tables .....	170
Water Supply and Hydropower Reliability .....	171
Flow and Storage Frequency Analyses .....	175
Reservoir Contents, Drawdown Duration, and Storage Reliability .....	179
Summary Tables .....	181
Water Budget Tables .....	183
<b>Chapter 6 Auxiliary Special-Purpose Modeling Features .....</b>	<b>189</b>
SIM Output Files .....	189
Auxiliary Software .....	192
Yield versus Reliability Relationships Including Firm Yield .....	194
Stream Flow Availability in Water Rights Priority Sequence .....	197
Beginning-Ending Storage Options .....	202
Tables Summarizing Water Right, Control Point, and Reservoir Input Data .....	204
General Modeling Framework for Applying WRAP .....	204
HYD Stream Flow Adjustments Using SIM Simulation Results to Develop SIM Hydrology Datasets .....	206
<b>Chapter 7 Detecting Errors and Irregularities in Data Files .....</b>	<b>213</b>
Locating Errors in SIM Input Data .....	213
Locating Errors in the SIM Output File .....	224
Locating Errors in TABLES Input Data .....	226
Locating Errors in HYD Input Data .....	226
HEC-DSS Trace Messages .....	231
<b>References .....</b>	<b>233</b>
<b>Appendix A Glossary .....</b>	<b>235</b>
<b>Appendix B SIM/TABLES Examples .....</b>	<b>243</b>
<b>Appendix C HYD Examples .....</b>	<b>283</b>

## LIST OF FIGURES

1.1	Texas WAM System River Basins .....	8
1.2	Major Rivers of Texas .....	10
2.1	Reservoir/River System Schematic .....	18
2.2	Outline of WRAP-SIM Simulation .....	23
2.3	Control Point Schematic for Example 1 .....	26
2.4	Control Point Schematic for Example 2 .....	32
3.1	Gage (Known-Flow) and Ungaged (Unknown Flow) Control Points .....	63
3.2	System with Negative Incremental Stream Flows .....	75
4.1	Reservoir Pools and Zones .....	111
4.2	Storage Zones for Defining Multiple-Reservoir Release Rules .....	112
4.3	Multiple Reservoir System .....	115
4.4	System Schematic for Example 10 in Appendix B .....	145
5.1	Time Series Plot Created with HEC-DSSVue .....	170

## LIST OF TABLES

1.1	WRAP Programs .....	3
1.2	Texas WAM System Models .....	9
2.1	Variables in the WRAP-SIM Output File .....	20
2.2	Organization of Model Documentation .....	22
2.3	Water Rights Information for Example 1 .....	26
2.4	Water Rights Simulation Results for Example 1 .....	27
2.5	Streamflow for the Month at Each Control Point for Example 1 .....	27
2.6	WRAP-SIM Input File for Example 2 .....	34
2.7	TABLES Input File for Example 2 .....	34
2.8	First Year of SIM Output File for Example 2 .....	35
2.9	TABLES Output File for Example 2 .....	36
3.1	Capabilities Provided by Program HYD .....	49
3.2	Methods for Establishing Stream Flow Inflows .....	60
3.3	Incremental Naturalized Streamflow Example .....	76
3.4	Available Stream Flows for the Example .....	76
4.1	Classification of Water Right Features .....	95
4.2	Water Right Types 1, 2, 3, 4, 5, 6, and 7 .....	104
4.3	Hydropower Factor for Alternative Sets of Units .....	129
5.1	Summary of SIM Simulation Results Variables in OUT File Output Records .....	159
5.2	Organization of Main SIM Output File .....	160
5.3	Water Right Output Record .....	160
5.4	Control Point Output Record .....	161
5.5	Reservoir/Hydropower Output Record .....	161
5.6	Beginning of OUT File for Example in Fundamentals Manual .....	163

## LIST OF TABLES (Continued)

5.7	Outline of Program TABLES Features .....	166
5.8	Example of a Time Series Table with Annual Rows and Monthly Columns .....	168
5.9	Example of a Time Series Table with Columnar Format .....	169
5.10	Reliability Table from the Example in the Fundamentals Manual .....	173
5.11	Hydropower Reliability Table from the Example in the Fundamentals Manual .....	173
5.12	2FRE Frequency Table from the Example in the Fundamentals Manual .....	176
5.13	2FRQ Frequency Table from the Example in the Fundamentals Manual .....	176
5.14	Frequency Factors for the Normal Probability Distribution .....	178
5.15	Beginning of Table of Reservoir Storage Content as Percentage of Capacity .....	180
5.16	Reservoir Storage Drawdown Duration Table .....	181
5.17	Reservoir Storage Reliability Table .....	181
5.18	Summary Table for a Control Point .....	182
5.19	Beginning of Control Point Water Budget Tabulation .....	184
5.20	River Basin Water Budget for Example in Fundamentals Manual .....	184
5.21	Monthly Volumes in the Control Point Water Budget Table .....	185
5.22	Summary Water Budget for the Entire River Basin(s) .....	186
6.1	SIM Output Files .....	190
6.2	Example SIM Yield-Reliability Output Table .....	195
6.3	Beginning of Example ZZZ File Created with ZZ Record .....	198
6.4	4ZZZ Time Series Table for the Example .....	200
6.5	4ZZF Frequency Analysis Table for the Example .....	201
7.1	SIM Trace Messages on Monitor .....	214
7.2	Information Recorded in Message File for Various Values of ICHECK .....	215
7.3	SIM Trace Messages Written to Message File .....	216
7.4	SIM Error Messages .....	219
7.5	SIM Warning Messages .....	222
7.6	HYD Trace Displayed on Monitor .....	227
7.7	Trace Information Copied to Message File for Various Values of ICHECK .....	227
7.8	HYD Trace Messages Written to HMS File .....	228
7.9	HYD Error Messages .....	230
7.10	HYD Warning Messages .....	231
7.11	DSS Message Levels .....	232

## ACKNOWLEDGEMENTS

Development of the WRAP modeling system has been an evolutionary process accomplished under the auspices of several sponsors. Many agencies, firms, and individuals have contributed to development and improvement of the model. The original WRAP, initially called TAMUWRAP, stemmed from a 1986-1988 research project at Texas A&M University, entitled *Optimizing Reservoir System Operations*, which was sponsored by a federal/state cooperative research program administered by the U.S. Geological Survey and Texas Water Resources Institute. The Brazos River Authority served as the nonfederal sponsor. Major improvements in the model were accomplished during 1990-1994 in conjunction with TAMU research projects sponsored by the Texas Water Development Board through the TWRI and by the Texas Advanced Technology Program administered by the Texas Higher Education Coordinating Board. Texas Natural Resource Conservation Commission support of WRAP actually began in 1996 before the 1997 Senate Bill 1. The model was greatly expanded and improved during 1997-2003 under TNRCC/TCEQ sponsorship pursuant to the 1997 Senate Bill 1 enacted by the Texas Legislature and subsequent legislation. The TNRCC was renamed the Texas Commission on Environmental Quality in 2002. The U.S. Army Corps of Engineers Fort Worth District during 2001-2005 also sponsored continued development of modeling capabilities. WRAP is being further expanded and improved during 2005-2008 under the auspices of the TCEQ. The TWDB also sponsored additional improvements during 2007-2008.

WRAP was applied to the 23 river basins of Texas by several consulting engineering firms working for the TNRCC/TCEQ, in coordination with the TWDB and Texas Parks and Wildlife Department, during development of the statewide Water Availability Modeling (WAM) System authorized by the 1997 Senate Bill 1. The Center for Research in Water Resources at the University of Texas at Austin provided GIS support for this effort. Since completion of the WAM System river basin models, the agencies and consulting firms are continuing to apply the models in support of permitting, planning, and other water management activities. The experience gained by the water management professionals of these agencies and consulting firms and their ideas for model improvements have greatly contributed to the development of WRAP.

Many graduate students at Texas A&M University have used WRAP in courses and research projects. The former students acknowledged here made major contributions to development of the modeling system working as graduate research assistants and focusing their thesis or dissertation research on WRAP related topics. Publications resulting from their work are cited in Chapter 1. Former graduate student researchers contributing to WRAP development include: W. Brian Walls, M.S. 1988; David D. Dunn, M.S. 1993; Anilkumar R. Yerramreddy, M.S. 1993; Gerardo Sanchez-Torres, Ph.D. 1994; Emery D. Sisson, M.S. 1999; A. Andres Salazar, Ph.D. 2002, Hector E. Olmos, M.S. 2004, and Ganesh Krishnamurthy, M.S., 2005. Ph.D. students Richard J. Hoffpauir, Chi Hun Lee, and Tae Jin Kim are currently working on further improvements to WRAP. Richard Hoffpauir has worked for several years both as a researcher expanding WRAP capabilities and as a consultant applying the modeling system. David Dunn, P.E., has contributed to the evolution of WRAP since the early 1990's, initially as a graduate student at TAMU, followed by an employment period at the USGS, and since then at HDR Engineering, Inc., participating in the TCEQ WAM System development and various planning and research studies. Andres Salazar and Hector Olmos have also upon graduation continued WRAP development/application efforts as civil engineers at Freese and Nichols, Inc.





## CHAPTER 1 INTRODUCTION

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

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

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

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

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

### **WRAP Documentation**

This *Reference Manual* and companion *Users Manual*, a *Supplemental Manual* covering additional features, and an introductory *Fundamentals Manual* document WRAP.

*Reference Manual for the Water Rights Analysis Package (WRAP) Modeling System*, TWRI TR-255, Fourth Edition, March 2008.

*Users Manual for the Water Rights Analysis Package (WRAP) Modeling System*, TWRI TR-256, Fourth Edition, March 2008.

*Fundamentals of Water Availability Modeling with WRAP*, TWRI TR-283, Fourth Edition, March 2008. (*Fundamentals Manual*)

*Conditional Reliability, Sub-Monthly Time Step, Flood Control, and Salinity Features of WRAP*, TWRI TR-284, First Edition, September 2006. (*Supplemental Manual*)

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

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

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

Additional features of the WRAP modeling system developed during 2002-2008 provide expanded capabilities for conditional reliability, flood control, and salinity modeling, and use of smaller time steps in the simulation. Daily or other sub-monthly time step options may be used along with flow forecasting and routing features. The expanded modeling capabilities are documented in the fourth report listed above which serves as a supplemental combined reference and users manual. The features covered in the *Supplemental Manual* build upon and extend the modeling capabilities covered by the basic *Reference and Users Manuals*.

Numerous computer models for analyzing reservoir/river system management have been reported in the published literature and unpublished agency documents. A state-of-the-art review of reservoir/river system modeling capabilities is presented in the report (Wurbs 2005):

*Comparative Evaluation of Generalized Reservoir/River System Models*,  
Texas Water Resources Institute, Technical Report 282, April 2005.

This review is designed to (1) assist practitioners in selecting and applying generalized models in various types of situations and (2) support continuing research and development efforts in improving modeling capabilities. Modeling methods and strategies are explored and several generalized river/reservoir management modeling systems, including WRAP, are compared.

## WRAP Programs

WRAP is a set of computer programs. Executable files are distributed for use on desktop computers operating under Microsoft Windows. Recent versions of the Fortran programs have been compiled with Compaq and Intel Visual Fortran compilers within the Microsoft Visual Studio Integrated Development Environment. The code conforms to both Fortran 95 and 2003 standards. A *Programming Manual* provides information useful in examining or modifying the Fortran code but not necessary for applying the modeling system. The public domain executable programs and documentation may be freely copied. Table 1.1 summarizes the function of each program and indicates whether it is documented by this *Reference Manual* and accompanying *Users Manual* or by the previously cited *Supplemental Manual* covering expanded modeling capabilities.

Table 1.1  
WRAP Programs

Program	Filename	Function	Documentation
WinWRAP	WinWRAP.exe	Microsoft Windows interface	Ref & User Manuals
TABLES	TAB.exe	Post-simulation summary tables, reliability indices, frequency tables	Ref & User Manuals & Supplemental Man
WRAP-SIM	SIM.exe	Monthly simulation model	Ref & User Manuals
WRAP-SIMD	SIMD.exe	Simulation model with monthly or sub-monthly time intervals	Supplemental Manual
WRAP-SALT	SALT.exe	Salinity simulation model	Supplemental Manual
WRAP-HYD	HYD.exe	Monthly hydrology data	Ref & User Manuals
WRAP-DAY	DAY.exe	Sub-monthly hydrology data	Supplemental Manual

The modeling system documented by this basic *Reference Manual* and companion *Users Manual* includes the following programs.

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

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

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

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

The following programs are not covered in the basic *Reference and Users Manuals* but rather are documented by the *Supplemental Manual* covering expanded modeling capabilities.

*SIMD* (*D* for daily) is an expanded version of *SIM* that includes features for sub-monthly time steps, flow disaggregation, flow forecasting and routing, and flood control operations along with all of the capabilities of *SIM*.

*DAY* assists in developing sub-monthly (daily) time step hydrology input for *SIMD* including disaggregating monthly flows to sub-monthly time intervals and determining routing parameters.

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

### WinWRAP User Interface

The Fortran programs are compiled as separate individual programs, which may be executed independently of each other without *WinWRAP*. However, the *WinWRAP* user interface program facilitates running all of the WRAP programs within Microsoft Windows in an integrated manner along with use of Microsoft programs to access and edit input and output files and use of HEC-DSSVue to plot and/or otherwise analyze simulation results. The *WinWRAP* interface connects executable programs and data files. The model user must create or obtain previously created files describing hydrology and water management for the river basin or region of concern along with other related information. The programs are connected through various input/output files. Certain programs create files with intermediate results to be read by other programs. File access occurs automatically, controlled by the software.

### *SIM* and *SIMD* Versions of the Simulation Model

The simulation program *SIM* performs the river/reservoir/use system water allocation computations using a monthly time step. *SIMD* contains all of the capabilities of the monthly time step *SIM*, plus options for synthesizing sub-monthly time step stream flows, flow forecasting and Muskingum routing, and simulating reservoir operations for flood control. Although any sub-monthly time interval may be used in *SIMD*, the model is called the daily version of *SIM* since the day is the default sub-monthly time step expected to be adopted most often.

*SIMD* duplicates simulation results for datasets prepared for *SIM*. The expanded version *SIMD* may be viewed as replacing *SIM*. However, *SIM* is being maintained as a separate program. The *SIM* program is complex, and the additional features make *SIMD* significantly more complex. *SIM* has been applied extensively as a component of the Texas WAM System. The basic *SIM* may continue to be used in ongoing applications of the Texas WAM System datasets that do not need the expanded modeling capabilities.

The conditional reliability modeling features covered in the supplemental expanded capabilities manual are incorporated in both *SIM* and *SIMD*. The *SIMD* sub-monthly time step, disaggregation of monthly to daily flows, flow forecasting, flow routing, and flood control reservoir operations features covered in the supplemental manual are provided only by *SIMD*, not *SIM*. *SIMD* flow forecasting involves consideration of future stream flows over a specified forecast period in making water supply diversion and multiple-purpose reservoir system operating decisions. Methodologies are provided for routing of stream flow adjustments.

### HYD and DAY Pre-Simulation Hydrology Programs

Program *HYD* assists in developing hydrology input for *SIM*, which consists of sequences of monthly naturalized stream flows and reservoir net evaporation-precipitation rates. *HYD* is the only program not affected by the expanded capabilities covered in the *Supplemental Manual*.

The program *DAY* documented in the *Supplemental Manual* provides a set of computational routines that facilitate developing *SIMD* hydrology input related to sub-monthly time steps. The *DAY* routines facilitate disaggregation of monthly flows to sub-monthly time intervals and calibrating routing parameters.

### SALT Simulation Model

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

### TABLES Organization of Simulation Results

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

## **Auxiliary Software**

The WRAP programs provide comprehensive computational capabilities but have no editing or graphics capabilities. The user's choice of auxiliary editing and graphics software may be adopted for use with WRAP. The only required auxiliary software is an editor such as Microsoft WordPad. However, WRAP modeling and analysis capabilities are enhanced by use of other supporting software for developing input datasets and plotting simulation results, such as Microsoft Excel, HEC-DSSVue, and ArcGIS.

### Microsoft Programs

Programs distributed by the Microsoft Corporation with its Windows and Office Systems are widely used. WordPad and Notepad are used routinely in editing WRAP input files and viewing simulation results. Excel provides both graphics and computational capabilities and has been extensively applied with WRAP. These programs are accessed directly from the *WinWRAP* interface. *TABLES* has options for tabulating essentially any of the time series variables included in the *SIM*, *SIMD*, and *SALT* simulation results in a format designed to be conveniently accessed by Microsoft Excel for plotting or other purposes.

### Hydrologic Engineering Center HEC-DSS and HEC-DSSVue

The Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE) has developed a suite of generalized hydrologic, hydraulic, and water management simulation models that are applied extensively by numerous agencies and consulting firms throughout the United States and abroad. The HEC-DSS (Data Storage System) is used routinely with HEC simulation models and with other non-HEC modeling systems as well. Multiple simulation models share the same graphics and data management software as well as a set of basic statistical and arithmetic routines. A HEC-DSS Excel data exchange add-in is also available from the HEC for transporting data between Microsoft Excel and HEC-DSS (Hydrologic Engineering Center 2003).

Database management and graphics capabilities provided by the HEC-DSS are oriented particularly toward voluminous sets of sequential data such as time series (Hydrologic Engineering Center 1995). The HEC-DSS Visual Utility Engine (HEC-DSSVue) is a graphical user interface program for viewing, editing, and manipulating data in HEC-DSS files (Hydrologic Engineering Center 2005). The public domain HEC-DSSVue software and documentation may be downloaded from the Hydrologic Engineering Center website. <http://www.hec.usace.army.mil/>

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. The WRAP executable programs include options for writing the *SIM*, *SIMD*, or *SALT* simulation results as HEC-DSS files. Hydrology input data stored as a DSS file can also be read by the WRAP simulation programs. HEC-DSSVue provides very convenient capabilities for graphical displays of WRAP simulation results. The many HEC-DSSVue mathematical and statistical computational routines may also be pertinent to manipulation and analysis of WRAP simulation results. HEC-DSSVue can be accessed directly through WinWRAP.

### ArcGIS and ArcMap WRAP Display Tool

Geographic information systems (GIS) such as ESRI's ArcGIS (<http://www.esri.com>) are useful in dealing with spatial aspects of compiling WRAP input data and displaying simulation results. Arc Hydro is a data model that operates within ArcGIS and provides a set of tools designed specifically for hydrology and water resources applications (<http://www.crrwr.utexas.edu/giswr/>; Maidment 2002). Gopalan (2003) describes development of ArcGIS tools at the Center for Research in Water Resources at the University of Texas to determine drainage areas and other watershed parameters and the spatial connectivity of control points for the WRAP input datasets for the Texas WAM System. Use of GIS tools to develop WRAP input data for the Texas WAM System is noted in the following section and discussed further in Chapter 3.

An ArcGIS tool for displaying WRAP simulation results was initially developed at Texas A&M University (Olmos 2004) and subsequently expanded at the University of Texas (Center for Research in Water Resources 2007) for the TCEQ. The WRAP Display Tool functions as a toolbar within the ArcMap component of ArcGIS. Ranges of water supply reliabilities, flow and storage frequencies, and other simulation results are displayed by control point locations as a color coded map. Time series graphs of WRAP-SIM output variables can also be plotted. Customization capabilities as well as standard WRAP output data features are provided.

## **Texas WAM System**

Senate Bill 1, Article VII of the 75<sup>th</sup> Texas Legislature in 1997 directed the Texas Natural Resource Conservation Commission (TNRCC) to develop water availability models for the 22 river basins of the state, excluding the Rio Grande. Models for six river basins were to be completed by January 2000, and the 16 others completed by January 2002. Subsequent legislation authorized modeling of the Rio Grande Basin. The Water Availability Modeling (WAM) Project was conducted collaboratively by the TNRCC (as lead agency), Texas Water Development Board (TWDB), Texas Parks and Wildlife Department (TPWD), consulting engineering firms, and university researchers, in coordination with the water management community. Effective September 2002, the TNRCC was renamed the Texas Commission on Environmental Quality (TCEQ). The resulting WAM System includes databases and data management systems, the generalized WRAP model, input datasets, and simulation results for all of the river basins of Texas (TNRCC 1998; Sokulsky, Dacus, Bookout, Patek 1998; Wurbs 2005). The water management and engineering professionals from the agencies and consulting firms responsible for implementing the Texas WAM System contributed numerous ideas for expanding and improving WRAP along with testing methodologies through actual applications.

During 1997-1998, the TNRCC, TWDB, TPWD, and a team of consulting firms evaluated available river/reservoir system simulation models to select a generalized model to adopt for the statewide water availability modeling system (TNRCC 1998). This study resulted in adoption of WRAP, along with recommendations for modifications. WRAP was greatly expanded and improved during 1997-2003 and 2005-2008 at Texas A&M University under interagency agreements between the TNRCC/TCEQ and Texas A&M University System.

Consulting engineering firms working under contracts with the TCEQ developed WRAP input datasets and performed simulation studies for all of the river basins of the state during 1998-2003. Parsons Engineering Science, R. J. Brandes Company, HDR Engineering, Freese and Nichols, Inc., Espey Consultants, Inc., and Brown and Root were the primary contractors. Other consulting firms assisted as subcontractors. Individual firms or teams of firms modeled individual river basins or groups of adjacent basins. The Sulphur, Neches, Nueces, San Antonio, and Guadalupe were the initial river basins modeled during 1998-1999. Work on the Trinity and San Jacinto River Basins and adjoining coastal basins was initiated in 1999. Work on the Brazos River Basin was initiated in early 2000, with the remainder of the 22 basins following shortly thereafter. Initial modeling of the 22 river basins was completed by 2002. The Rio Grande, the 23rd and last basin, was modeled in 2002-2003. Upon completion of the models for each river basin, water rights permit holders were provided information regarding reliabilities associated with their water rights. WRAP input datasets and reports documenting the simulation studies are available from the TCEQ.

The Center for Research in Water Resources (CRWR) at the University of Texas, under contract with the TCEQ, developed an ArcView/ArcInfo based geographic information system for delineating the spatial connectivity of pertinent sites and determining watershed parameters required for distributing naturalized stream flows (Hudgens and Maidment 1999; Mason and Maidment 2000; Figurski and Maidment 2001), which was later updated/improved using the new ArcGIS Hydro Data Model (Maidment 2002; Gopalan 2003). The watershed parameters are drainage area,



curve number (representing soil type and land use), and mean precipitation. The CRWR applied the GIS to the various river basins and provided the resulting information to the TCEQ and consulting firms responsible for modeling each of the river basins.

Texas has 15 major river basins and eight coastal basins lying between the lower reaches of the major river basins. The Texas WAM System includes 21 WRAP input datasets covering the 23 river basins. Three of the 21 datasets combine two river basins, and one basin is divided into two datasets. The water rights in the datasets are updated as the TCEQ approves applications for new permits or revisions to existing permits. Other aspects of the datasets also continue to be refined. The datasets are available at the TCEQ WAM website. Information describing the authorized use datasets as of January 2008 is tabulated in Table 1.2. The map number in the first column of Table 1.2 refers to the river basins shown in Figure 1.1.

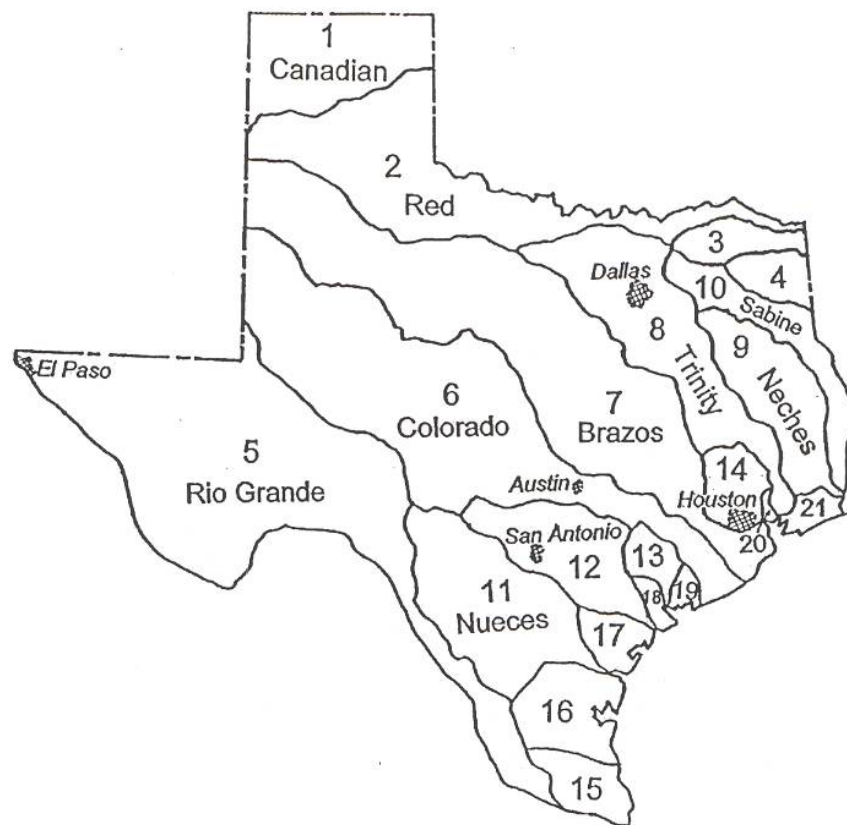


Figure 1.1 Texas WAM System River Basins

The 21 datasets as of January 2008 contained 10,512 water right *WR* records and 662 instream flow *IF* records (11,174 total model water rights) representing almost 8,000 water right permits. Multiple water rights in the model may represent a single complex permit. The period-of-analysis is at least 50 years for all of the basins, with the longest being 1940-2000. The datasets contain 13,272 control points. About 498 primary control points, usually representing gaging stations, have naturalized flows included in the data. The datasets model the approximately 3,435 reservoirs for which a water right permit has been issued. Over 90 percent of the total capacity of the 3,435 reservoirs is contained in the approximately 210 reservoirs that

have conservation capacities exceeding 5,000 acre-feet. Storage capacities for the reservoirs are cited in their water right permits. Most of the larger reservoirs have undergone sediment surveys since construction. In developing the WAM datasets, elevation-storage-area tables for most of the major reservoirs having conservation storage capacities of at least 5,000 acre-feet were assembled for both permitted and estimated year 2000 conditions of sedimentation. Generalized storage-area relationships were adopted in each river basin for the numerous smaller reservoirs.

Table 1.2  
Texas WAM System Models

Map ID	Major River Basin or Coastal Basin	Period of Analysis	Number of					Reservoir Storage Capacity (acre-feet)	Mean Natural Flow (ac-ft/yr)
			Primary Control Points	Total Control Points	Model Water Rights	Instream Flow Rights	Model Reservoirs		
1	Canadian River Basin	1948-98	12	85	56	0	47	966,000	190,000
2	Red River Basin	1948-98	47	447	489	103	245	4,124,000	11,049,000
3	Sulphur River Basin	1940-96	8	83	85	5	53	753,000	2,498,000
4	Cypress Bayou Basin	1948-98	10	189	163	1	91	902,000	1,748,000
5	Rio Grande Basin	1940-00	55	957	2,584	4	113	23,918,000	3,724,000
6	Colorado River Basin and Brazos-Colorado Coastal	1940-98	45	2,395	1,922	86	511	4,763,000	2,999,000
7	Brazos River and San Jacinto-Brazos Coastal	1940-97	77	3,830	1,634	122	670	4,695,000	6,357,000
8	Trinity River Basin	1940-96	40	1,334	1,169	23	703	7,504,000	6,879,000
9	Neches River Basin	1940-96	20	318	333	17	176	3,904,000	6,235,000
10	Sabine River Basin	1940-98	27	376	310	21	207	6,401,000	6,887,000
11	Nueces River Basin	1934-96	41	542	373	30	121	1,040,000	868,000
12	Guadalupe and San Antonio River Basins	1934-89	46	1,349	860	184	237	808,000	2,101,000
13	Lavaca River Basin	1940-96	7	185	71	30	22	235,000	943,000
14	San Jacinto River Basin	1940-96	16	411	148	13	114	637,000	2,207,000
15	Lower Nueces-Rio Grande	1948-98	16	119	70	6	42	101,700	249,000
16	Upper Nueces-Rio Grande	1948-98	13	81	34	2	22	11,000	342,000
17	San Antonio-Nueces	1948-98	9	53	12	2	9	1,480	565,000
18	Lavaca-Guadalupe Coast	1940-96	2	68	10	0	0	0	134,000
19	Colorado-Lavaca Coastal	1940-96	1	111	27	4	8	7,230	142,000
20	Trinity-San Jacinto	1940-96	2	94	24	0	13	4,880	181,000
21	Neches-Trinity Coastal	1940-96	4	245	138	9	31	58,000	607,000

Several of the river systems shown in Fig. 1.2 are shared with neighboring states. The Rio Grande is shared with Mexico. For the interstate and international river basins, hydrology and water management in neighboring states and Mexico are considered to the extent necessary to assess water availability in Texas. The models reflect two international treaties and five interstate compacts as well as the two Texas water rights systems administered by the TCEQ. The water rights system allocating the Texas share of the waters of the lower Rio Grande is significantly different from the water rights system for the rest of Texas (Wurbs 2004).



Figure 1.2 Major Rivers of Texas

Along with compiling the WRAP input datasets, the TCEQ contractors performed simulations for alternative scenarios reflecting combinations of premises regarding water use, return flows, and reservoir sedimentation. Eight defined scenarios were simulated for all of the river basins. Other scenarios were added for particular basins. The following two scenarios are routinely adopted for both water right permit applications and planning studies.

- The authorized use scenario is based on the following premises.
  1. Water use targets are the full amounts authorized by the permits.
  2. Full reuse with no return flow is assumed.
  3. Reservoir storage capacities are those specified in the permits, which typically reflect no sediment accumulation.
  4. Term permits are not included.
  
- The current use scenario is based on the following premises.
  1. The water use target for each right is based on the maximum annual amount used in any year during a recent ten year period.
  2. Best estimates of actual return flows are adopted.
  3. Reservoir storage capacities and elevation-area-volume relations for major reservoirs reflect year 2000 conditions of sedimentation.
  4. Term permits are included.

The WAM System is applied by water management agencies and their consultants in planning studies and preparation of permit applications. TCEQ staff applies the modeling system in evaluating the permit applications. The TWDB, regional planning committees, and their consultants apply the modeling system in regional and statewide planning studies also established by the 1997 Senate Bill 1. Agencies and consulting firms use the modeling system in various other types of studies as well.

### **Model Development Background**

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

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

#### **Early Versions of the WRAP Programs**

A university research project, entitled *Optimizing Reservoir Operations in Texas*, was performed in 1986-1988 as a part of the cooperative federal/state research program of the Texas Water Resources Institute and U.S. Geological Survey. The Brazos River Authority served as the nonfederal sponsor. The research focused on formulating and evaluating storage reallocations and other reservoir system operating strategies and developing improved modeling capabilities for analyzing hydrologic and institutional water availability. A system of 12 reservoirs in the Brazos River Basin, operated by the U.S. Army Corps of Engineers Fort Worth District and the Brazos River Authority, provided a case study. Several computer simulation models were applied. The need for a generalized water rights analysis model became evident. The original version of the WRAP model, called the *Texas A&M University Water Rights Analysis Program (TAMUWRAP)*, was developed and applied in the portion of the Brazos River Basin study documented by Wurbs, Bergman, Carriere, and Walls (1988), Walls (1988), and Wurbs and Walls (1989).

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

The original *TAMUWRAP* was replaced by *WRAP2* and *TABLES*, reflecting significant improvements building on the same fundamental concepts. The computational algorithms were refined, additional capabilities were added, the input data format was changed, and the output format was totally restructured. *WRAP3* was more complex than *WRAP2* and provided expanded capabilities, particularly in regard to simulating multiple-reservoir, multiple-purpose reservoir system operations. The revisions involved coding completely new computer programs. Model

development and application to the Brazos River Basin are described by Dunn (1993) and Wurbs, Sanchez-Torres, and Dunn (1994). Further minor revisions were made in conjunction with a water availability modeling project for the San Jacinto River Basin performed at TAMU for the TNRCC in 1996. The *WRAP2*, *WRAP3*, and *TABLES* package is documented by Wurbs and Dunn (1996).

*WRAPNET* was developed in conjunction with a research study to evaluate the relative advantages and disadvantages of adopting a generic network flow programming algorithm for WRAP as compared to ad hoc algorithms developed specifically for WRAP (Yerramreddy 1993; Wurbs and Yerramreddy 1994). Network flow programming is a special computationally efficient form of linear programming that has been adopted for a number of other similar models (Wurbs 2005). *WRAPNET* reads the same input files as *WRAP2* and provides the same output, but the simulation computations are performed using a network flow programming algorithm. *TABLES* is used with *WRAPNET* identically as with *WRAP2* or *WRAP3* or the later *WRAP-SIM*. Although network flow programming was demonstrated to be a viable alternative modeling approach, the model-specific algorithms were concluded to be advantageous for the WRAP model.

Development of *WRAP-SALT* was motivated by natural salt pollution in Texas and neighboring states (Wurbs et al. 1994; Sanchez-Torres 1994; Wurbs and Sanchez-Torres 1996, Wurbs 2002). The model was applied to the Brazos River Basin. The initial *WRAP-SALT* was an expanded version of *WRAP3* and *TABLES* with features added for simulating salt concentrations and their impacts on water supply reliabilities. Sequences of monthly salt loads were input along with the naturalized stream flows. Water availability was constrained by both salt concentrations and water quantities. The current *SALT* provides similar modeling capabilities but has been completely rewritten. Whereas the original *WRAP-SALT* integrated the salinity computations internally within *WRAP3*, the current *SALT* is a separate program that reads a *SIM* output file.

### Texas WAM System

Development of WRAP has been motivated by the implementation of a water rights permit system in Texas during the 1970's and 1980's and the creation of the previously discussed statewide Water Availability Modeling (WAM) System during 1997-2003 to support administration of the water rights system. Surface water law in Texas evolved historically over several centuries (Wurbs 2004). Early water rights were granted based on various versions of the riparian doctrine. A prior appropriation system was later adopted and then modified. The Water Rights Adjudication Act of 1967 merged the riparian water rights into the prior appropriation system. The allocation of surface water has now been consolidated into a unified permit system. The water rights adjudication process required to transition to the permit system was initiated in 1967 and was essentially completed by the late 1980's.

As previously discussed, the 1997 Senate Bill 1 was a comprehensive water management legislative package addressing a wide range of issues including the need to expand statewide water availability modeling capabilities. The TCEQ, its partner agencies, and contractors developed the Texas WAM System during 1997-2003 pursuant to the 1997 Senate Bill 1 to support water rights regulatory and regional and statewide planning activities. Texas WAM System implementation efforts resulted in extensive modifications and many evolving versions of WRAP developed under 1997-2003 and 2005-2008 contracts between the TCEQ and Texas A&M University System.

## Modeling Capabilities Added Since Implementation of WAM System

The TCEQ has continued to improve and expand WRAP since implementation of the WAM System. The Fort Worth District of the U.S. Army Corps of Engineers also cosponsored ongoing efforts at TAMU during 2001-2005 to further expand WRAP under its congressionally authorized Texas Water Allocation Assessment Project. The TWDB sponsored additional improvements during 2007-2008. The TWRI and TAMU Civil Engineering Department have continued to support WRAP expansion efforts. The modeling capabilities covered by this *Reference Manual* and accompanying *Users Manual* include many significant improvements and new features added since completion of the initial TCEQ WAM System implementation project. The following additional major new modeling capabilities documented by the *Supplemental Manual* (Wurbs, Hoffpauir, Olmos, and Salazar 2006) are not covered in the *Reference and Users Manuals*.

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

The original *WRAP* uses a monthly time step. The expanded version allows each of the 12 months to be subdivided into any number of time intervals with the default being daily. Model 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. An adaptation of the Muskingum routing method has been added for use with smaller computational time steps. Calibration methods for determining routing parameters are included in the software package. Future time steps extending over a forecast period are considered in determining water availability. *TABLES* develops frequency relationships and reliability indices reflecting the sub-monthly time interval. *SIMD* sub-monthly results may also be aggregated to monthly values.

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

Natural salt pollution (Wurbs 2002) in several major river basins in Texas and neighboring states motivated addition of capabilities for tracking salt concentrations through river/reservoir systems for alternative water management/use scenarios. *SALT* reads water quantity data from a *SIM* or *SIMD* output file along with additional input data regarding salt concentrations and loads of flows entering the river system. The model computes concentrations of the water quality constituents in the regulated stream flows, diversions, and reservoir storage contents throughout the river basin. Options in *TABLES* organize the salinity simulation results.

## **Organization of the Reference and Users Manuals**

This *Reference Manual* and accompanying *Users Manual* cover the WRAP modeling system exclusive of the expanded modeling capabilities noted in the preceding section. As previously noted, a third *Supplemental Reference/Users Manual* documents the additional features not covered in the basic *Reference and Users Manuals*. The *Programming Manual* documenting the Fortran code for all the WRAP programs is designed to support software maintenance and improvement but is not necessary in applying the executable programs.

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

Chapters 1 and 2 and Appendix A of this *Reference Manual* provide a general overview of WRAP. Chapter 1 introduces the model and its documentation and describes its origins. Chapter 2 covers modeling capabilities and methodologies from a general overview perspective. Appendix A is a glossary of terms used in the manuals.

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

Chapters 5 and 6 describe *SIM* simulation results and the use of *TABLES* and auxiliary software to organize and analyze simulation results. The time series variables computed in the *SIM* simulation are defined. Special *SIM* auxiliary analysis features are outlined. Capabilities provided by *TABLES* for developing simulation results tables, summaries, water budgets, reliability indices, frequency relationships, and tabulations for transport to Excel and HEC-DSSVue are explained.

Appendix B consists of input and output for several *SIM* and *TABLES* examples. Examples illustrating *HYD* are presented as Appendix C. The *Fundamentals Manual* presents a larger, more realistic example. The input files for the examples are available in electronic format along with the executable programs. Learning WRAP is greatly facilitated by experimenting with the examples. The simulation computations can be readily tracked by examining simulation results. The examples provide simple datasets with easy-to-track numbers to which additional modeling options of interest can be added to explore their functionality.

## CHAPTER 2 OVERVIEW OF THE SIMULATION MODEL

### Modeling Capabilities

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

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

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

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



## Water Availability Modeling Process

The conventional water availability modeling process consists of two phases:

1. developing sequences of monthly naturalized stream flows covering the hydrologic period-of-analysis at all pertinent locations
  - a. developing sequences of naturalized flows at stream gaging stations [*WRAP-HYD*]
  - b. extending record lengths and filling in gaps to develop complete sequences at all selected gages covering the specified period-of-analysis [*Not included in WRAP*]
  - c. distributing naturalized flows from gaged to ungaged locations [*HYD or SIM*]
2. simulating the rights/reservoir/river system, given the input sequences of naturalized flows, to determine regulated and unappropriated flows, storage, reliability indices, flow-frequency relationships and related information regarding water supply capabilities
  - a. simulating the rights/reservoir/river system [*WRAP-SIM*]
  - b. computing water supply reliability and stream flow frequency indices and otherwise organizing/summarizing/displaying simulation results [*TABLES*]

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

*HYD* includes options to assist in adjusting gaged flows to obtain naturalized flows (Task 1a above). Naturalized flows may be distributed from gaged (or known-flow) locations to ungaged (unknown-flow) locations (Task 1c above) within either *HYD* or *SIM*. *WRAP* does not include regression methods to extend records or reconstitute missing data (Task 1b). Readily available spreadsheet and statistical software packages include regression analyses. Naturalized flows have been developed (Tasks 1a and 1b) for the Texas WAM System and are readily available for further application. Watershed parameters for distributing flows (Task 1c) are also incorporated in the Texas WAM System datasets.

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

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

### **Long-Term Simulation, Yield-Reliability, and Conditional Reliability Modeling Modes**

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

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

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

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

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

months or a year into the future are conditioned upon the preceding storage condition. The CRM mode supports short-term operational planning studies and seasonal or real-time reservoir/river system management. CRM procedures are explained in the *Supplemental Reference/Users Manual* (Wurbs, Hoffpauir, Olmos, and Salazar 2006).

### Control Point Representation of Spatial Configuration

The spatial configuration of a river/reservoir/water use system is represented in WRAP as a set of control points that represent pertinent sites in the river basin. Reservoirs, diversions, return flows, instream flow requirements, stream flows, evaporation rates, and other system features are assigned control points denoting their locations. Control points provide a mechanism to model spatial connectivity. The *CP* input record for each control point includes the identifier of the next control point located immediately downstream. Various computational routines in the model include algorithms allowing the computations to cascade downstream by control point. Spatial complexity in actual applications may range from a system modeled with a single control point to models with several control points to those with thousands of control points. The number of control points incorporated in the datasets for the river basins in the Texas WAM System listed in Table 1.2 range from 49 to over 3,000. Figure 2.1 below is a schematic of a river/reservoir/use system modeled as a set of 12 control points.

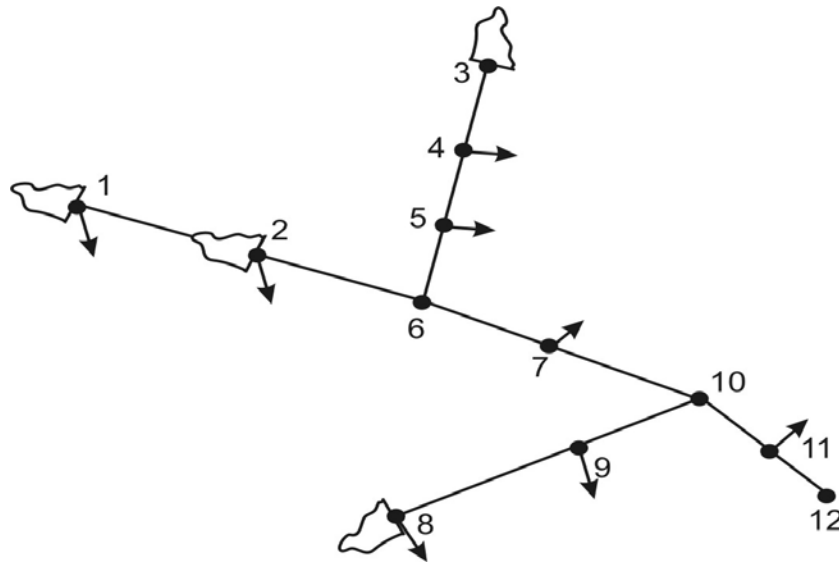


Figure 2.1 Reservoir/River System Schematic

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

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

### **Simulation Input**

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

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

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

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

## Simulation Results

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

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

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

Table 2.1  
Variables in the WRAP-SIM Output File

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

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

a control point record are the totals for all the rights assigned to the control point. The diversions and shortages on a water right output record are associated with a single *WR* input record.

As discussed in Chapter 5, the time series of monthly values of the variables listed in Table 2.1 are read by the post-simulation program *TABLES*, which in turn creates user-specified tables to organize, display, and summarize the simulation results. Some of the *TABLES* routines simply rearrange and tabulate, with appropriate table headings, selected data read from *SIM* input or output files. Other routines include computational algorithms, which may range from simple sums or statistics to more complex arithmetic operations. A reliability table for water supply diversion or hydroelectric energy targets includes volume reliabilities and period reliabilities for meeting various percentages of the target demands. Frequency tables are developed for naturalized flows, regulated flows, unappropriated flows, reservoir storage, and instream flow shortages. Reservoir storage may be also displayed as comparative tables of percentages of capacity and drawdown-duration tables. *TABLES* also creates tables organizing and summarizing water rights data read from a *SIM* input file. Options in *TABLES* also allow data to be tabulated in formats designed to facilitate convenient import to Microsoft Excel or HEC-DSSVue for further computations or graphs.

### Units of Measure

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

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

A set of computationally consistent (meters $\times$  km<sup>2</sup> = million m<sup>3</sup>) metric units is as follows:

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

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

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

## Organization of the Simulation Computations

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

Table 2.2  
Organization of Model Documentation

WRAP Program	<i>SIM</i>	<i>TABLES</i>	<i>HYD</i>
Explanation of model capabilities and methods	RM Ch 2-6	RM Ch 2,5,6	RM Chap 3,6
Detailed instructions for preparing input data	UM Ch 2-3	UM Chap 4	UM Chap 5
Example datasets	RM Appd B and Fundamentals Manual	RM Appd B	RM Appd C
Information regarding Fortran programs	Programming Manual		

### WRAP-SIM Simulation Overview

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

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

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

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

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

Figure 2.2 Outline of WRAP-SIM Simulation



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

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

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

### Steps in the WRAP-SIM Simulation

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

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

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

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

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

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

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

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

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

month storage are to be allocated to meet the three diversion requirements, satisfy reservoir net precipitation-evaporation, and refill the reservoir storage to capacity. The water use requirements are met to the extent allowed by available stream flows and beginning-of-month reservoir storage. The water rights are listed in priority order in Table 2.3 with their priorities being tabulated in column 3. The computations begin with WR-A, the most senior right. Water rights WR-B and WR-C are then considered in order of priority.

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

Table 2.3 Water Rights Information for Example 1

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

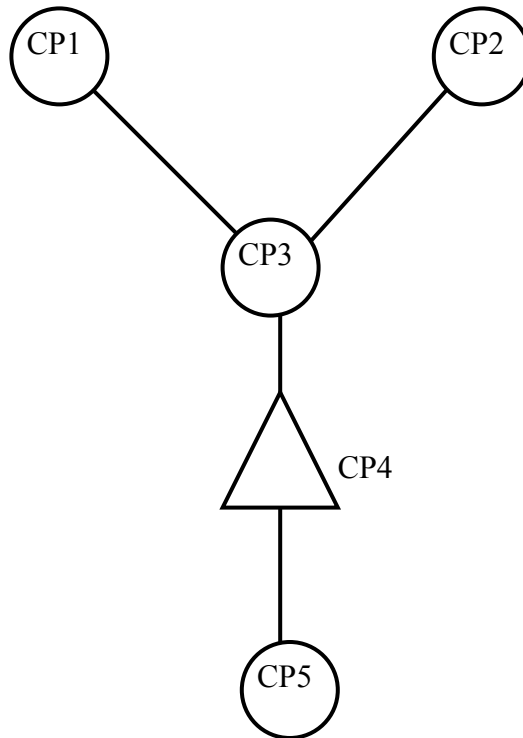


Figure 2.3 Control Point Schematic for Example 1

Table 2.4 Water Rights Simulation Results for Example 1

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

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

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

Stage 2 consists of determining the amount of water available this month for water right WR-A at control point CP4. The amount of stream flow available is the lesser of the naturalized flow at CP4 (80 ac-ft) and all downstream control points (100 ac-ft at CP5). Thus, for WR-A, the available stream flow this month is 80 ac-ft as shown in column 3 of Table 2.4. Beginning-of-month storage of 195 ac-ft is also available.

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

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

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

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

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

### Water Accounting Procedures

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

The stream flow depletion for a water right with reservoir storage will include the net volume of evaporation less precipitation. The stream flow depletion may also include water

taken to refill previously drawn-down reservoir storage. Conversely, water use requirements may be met by withdrawals from reservoir storage. The water accounting computations for a storage right include computation of reservoir net evaporation-precipitation volume. An input net evaporation minus precipitation depth is applied to the average water surface area, which is determined as a function of average storage during the period, determined by averaging the storage at the beginning and end of the period. An iterative algorithm is used since evaporation volume depends on end-of-period storage, which is a function of evaporation. Likewise, an iterative algorithm is used to determine hydroelectric power releases, which depend on head, which is a function of end-of-month storage.

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

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

where:

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

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

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

End-of-period storage depends upon all the rights associated with the reservoir. For a senior water right, the beginning-of-period storage can be impacted by the computations for the previous month for junior rights at the same reservoir. For a hydropower right, the actual beginning-of-period and end-of-period storages are used in the computations, even if the capacity associated with the right is exceeded due to other rights. For a diversion right, the beginning-of-period and end-of-

period storages used in the computations for that particular right are limited to not exceed the storage capacity associated with the right. Thus, the storage capacity for a junior right at a reservoir must be equal to or greater than the storage capacity of any senior right at the reservoir.

### **Constructing a Model with WRAP**

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

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

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

WRAP applications may be simple. A *SIM* input dataset may involve only a few types of records using relatively simple options. On the other hand, applications may be quite complex. River basin hydrology, water control facilities, water use requirements, institutional water allocation procedures, and management policies/practices for major river basins are complicated. Many varied options are incorporated in the generalized WRAP modeling system in order to provide flexible capabilities for analyzing a comprehensive range of river basin management situations. Complexities in applying WRAP are related primarily to (1) the numerous optional features available for modeling various complexities of water management and (2) the need to compile and

manage large amounts of data. Ingenuity is required to combine the appropriate WRAP options to model complex systems of rivers, reservoirs, and water rights. Significant time, effort, and expertise may be required to compile the voluminous input data, perform a simulation study, and analyze and interpret results.

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

The following Example 2 is a simple hypothetical application presented to introduce basic features of *SIM* and *TABLES*. The example combines title *T1*, *T2*, comment \*\*, job control data *JD*, use coefficient *UC*, control point *CP*, instream flow *IF*, water right *WR*, water right reservoir storage *WS*, storage volume *SV* versus surface area *SA*, end of data *ED*, inflow *IN*, and evaporation *EV* records, all stored in a DAT file with the filename Exam1.dat. This represents only 13 of the 50 *SIM* input record types outlined in the *Users Manual*, and many of the fields of these records remain blank, meaning various optional features are not used. However, the fundamental record types introduced by this simple example may be the only records needed to construct real-world models.

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

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

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



created by *TABLES* (filename Tab2.TAB) from the *SIM* output file (Exam2.OUT) summarizing the simulation results are shown in Table 2.9.

As shown in Figure 2.4, the spatial configuration is represented by two control points, CP1 and CP2. Of the three water rights, the environmental instream flow requirement of 1,000 acre-feet/month at CP2 has the highest priority (priority number 1). The 38,000 acre-feet/year run-of-river irrigation diversion right at CP2 is the most junior (priority number 3). The third right consists of a municipal diversion of 96,000 ac-ft/year from RES-A and refilling the storage capacity of 110,000 acre-feet. Annual instream flow and diversion requirements are distributed over the 12 months of the year using the use coefficients entered on *UC* records, except for the instream flow right which uses the default constant uniform distribution. The naturalized stream flows on the *IN* records are in units of acre-feet/month. The net evaporation-precipitation rates on the *EV* records are in inches. A multiplier factor of 0.08333 is included on the *CP* record for CP1 to convert to feet. A storage (acre-feet) versus water surface area (acres) relationship for reservoir Res-A is defined by *SV/SA* records.

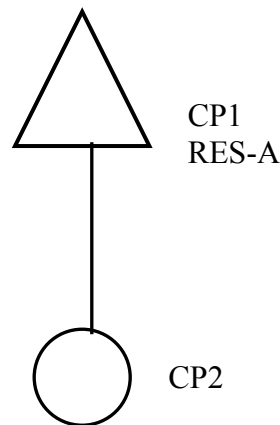


Figure 2.4 Control Point Schematic for Example 2

The system is simulated with *SIM*, and the simulation results are organized using program *TABLES*. The *TABLES* input file (filename Tab2.TIN) shown in Table 2.7 and *SIM* output file (Exam2.OUT) shown partially in Table 2.8 are read by *TABLES* to create file Tab2.OUT, which is reproduced as Table 2.9. The several sample tables shown in Table 2.9 illustrate some of the types and variations of tables that may be created by *TABLES* to organize and summarize simulation results.

Table 2.9 begins with two annual summary tables for control points CP1 and CP2. *TABLES* provides options to develop monthly and/or annual summary tables for control points, reservoirs, water rights, selected groups of water rights, or the entire river basin. Quantities from the summary tables are related by volume balances. For example, for simulation year 1955 at control point CP1:

$$\begin{aligned} \text{naturalized streamflow} + \text{return flow} &= \text{storage change} + \text{diversion} + \text{evaporation} + \text{regulated flow} \\ 276,920 \text{ ac-ft/yr} + 0 &= (94,677 - 55,772) + 96,000 + 19,479 + 122,536 \text{ ac-ft/yr} \end{aligned}$$

Stream flow depletions are:

$$\text{streamflow depletion} = \text{diversion} + \text{evaporation} + \text{storage refilling}$$

$$\text{CP1 1955 streamflow depletion} = 96,000 + 19,479 + (94,677 - 55,772) = 154,384 \text{ ac-ft/yr}$$

$$\text{CP2 1955 streamflow depletion} = \text{diversion} = 38,000 \text{ ac-ft/yr}$$

Since CP2 is the most downstream gage, the 1955 annual volume balance may be expressed as:

$$\text{naturalized flows} + \text{return flows} = \text{CP1 and CP2 streamflow depletions} + \text{CP2 regulated flows}$$

$$345,380 + 38,400 = 154,384 + 38,000 + 191,396$$

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

$$\text{period reliability} = [(24-8)/24] 100\% = 66.67\%$$

$$\text{volume reliability} = [(38,000-6,877)/38,000] 100\% = 81.90\%$$

The reliability table shows that the diversion at CP2 equals or exceeds 50 percent of the monthly target in 91.7 percent of the months. The annual diversion equals or exceeds 34,200 ac-ft/yr (90% of the annual target of 38,000 ac-ft/yr) during 33.3% of the three years of the period-of-analysis.

The first flow-frequency table in Table 2.9 (bottom of page 36) indicates that regulated monthly stream flows at CP2 vary from 1,000 ac-ft to 80,526 ac-ft, with a mean of 7,650 ac-ft. The regulated flow equals or exceeds 2,168 ac-ft during 75% of the 36 months. The second flow-frequency table is in an alternate format in which exceedance frequencies are determined for user-specified flow amounts. Frequency tables may be developed for naturalized, regulated, and unappropriated stream flows, reservoir storage, and instream flow shortage.

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

*TABLES* can also write the time series variables from the *SIM* simulation results, with or without optional adjustments, as binary DSS files which are read by HEC-DSSVue (Hydrologic Engineering Center 2005). *SIM* can also record results directly in a DSS file. DSS files can be read only by HEC-DSSVue or other HEC-DSS software. The primary motivation for converting *SIM* simulation results to records in a DSS file is to facilitate convenient plotting using HEC-DSSVue. However, the full spectrum of other HEC-DSS capabilities are available as well as graphics.

Table 2.6  
WRAP-SIM Input File for Example 2

```

T1 Example 2 - WRAP-SIM Input File Exam2.DAT
T2 Example 2 from Chapter 2 of the Reference Manual
JD      3      1954      1      -1      -1
JO      3
**
UC munic 0.06    0.06    0.07    0.07    0.08    0.10
UC      0.13    0.12    0.09    0.08    0.08    0.06
UC irrig 0.00    0.00    0.04    0.12    0.19    0.22
UC      0.22    0.15    0.05    0.01    0.00    0.00
**
CP  CP1      CP2      0.08333
CP  CP2      OUT      none
**
IF  CP2  12000      1      Instream Flow
WR  CP2  38000    irrig    3      Irrigation Right
WR  CP1  96000    munic    2      0.4      Municipal Right
WS Res-A 110000
**
SV Res-A      0      1030    3730    10800    27700    53400    92100    112000
SA      0      140     409     1150     2210     3100     4690     6160
ED
IN  CP1  1954  10200    6540    3710    7350    15100    904    112    328    972    2650    17300    1290
IN  CP2  1954  12700    7660    4760    9190    21400    1130    145    447    1220    3310    21800    1620
EV  CP1  1954    3.7     3.9     3.9     3.8     4.2     4.5     4.6     4.3     4.1     3.9     4     3.9
**
IN  CP1  1955    3390    3110    12900    42300    62700    76500    16900    21200    25700    8810    1560    1850
IN  CP2  1955    4160    3780    15800    51600    78000    96800    21200    26500    31400    11900    1930    2310
EV  CP1  1955    3.6     3.7     3.8     3.6     4.1     4.3     4.4     4.2     4     3.7     3.9     3.7
**
IN  CP1  1956    3290    8970    1570    2410    48900    5630    7990    3910    1090    1740    13700    14600
IN  CP2  1956    4090    11200    2140    3210    59300    7160    10060    4950    1380    2320    17100    18300
EV  CP1  1956    3.8     3.9     4.0     3.8     4.1     4.2     4.3     4.4     4.2     3.7     4.1     3.7

```

Table 2.7  
TABLES Input File for Example 2

```

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

```

Table 2.8  
First Year of SIM Output File for Example 2

WRAP-SIM (March 2008 Version) OUT Output File  
Example 2 - WRAP-SIM Input File Exam2.DAT  
Example 2 from Chapter 2 of the Reference Manual

1954	3	2	3	0	0	0	1.000								
IF 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00	0.00	0.00	1 1954	
1954 1	0.000	5760.000	1853.71	110000.00	7613.71	10200.00	0.00	Municipal Right				2304.00	0.00	0.00	
1954 1	0.000	0.000	0.00	0.00	0.00	6390.29	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	5760.000	1853.71	110000.00	7613.71	2586.29	0.00	10200.00	2586.29	0.00	0.00	0.00	0.00	0.00	
CP2	0.000	0.000	0.00	0.00	0.00	6390.29	2304.00	12700.00	7390.29	0.00	0.00	0.00	0.00	0.00	
IF 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00			0.00	0.00	2 1954	
1954 2	0.000	5760.000	1939.98	108840.02	6540.00	6540.00	0.00	Municipal Right				2304.00	0.00	0.00	
1954 2	0.000	0.000	0.00	0.00	0.00	2424.00	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	5760.000	1939.98	108840.02	6540.00	0.00	0.00	6540.00	0.00	0.00	0.00	0.00	0.00	0.00	
CP2	0.000	0.000	0.00	0.00	0.00	2424.00	2304.00	7660.00	3424.00	0.00	0.00	0.00	0.00	0.00	
IF 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00			0.00	0.00	3 1954	
1954 3	0.000	6720.000	1867.51	103962.50	3710.00	3710.00	0.00	Municipal Right				2688.00	0.00	0.00	
1954 3	0.000	1520.000	0.00	0.00	1520.00	2738.00	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	6720.000	1867.51	103962.50	3710.00	0.00	0.00	3710.00	0.00	0.00	0.00	0.00	0.00	0.00	
CP2	0.000	1520.000	0.00	0.00	1520.00	1218.00	2688.00	4760.00	2218.00	0.00	0.00	0.00	0.00	0.00	
IF 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00			0.00	0.00	4 1954	
1954 4	0.000	6720.000	1749.49	102843.01	7350.00	7350.00	0.00	Municipal Right				2688.00	0.00	0.00	
1954 4	1032.000	4560.000	0.00	0.00	3528.00	3528.00	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	6720.000	1749.49	102843.01	7350.00	0.00	0.00	7350.00	0.00	0.00	0.00	0.00	0.00	0.00	
CP2	1032.000	4560.000	0.00	0.00	3528.00	0.00	2688.00	9190.00	1000.00	0.00	0.00	0.00	0.00	0.00	
IF 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00			0.00	0.00	5 1954	
1954 5	0.000	7680.000	1989.38	108273.63	15100.00	15100.00	0.00	Municipal Right				3072.00	0.00	0.00	
1954 5	0.000	7220.000	0.00	0.00	7220.00	8372.00	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	7680.000	1989.38	108273.63	15100.00	0.00	0.00	15100.00	0.00	0.00	0.00	0.00	0.00	0.00	
CP2	0.000	7220.000	0.00	0.00	7220.00	1152.00	3072.00	21400.00	2152.00	0.00	0.00	0.00	0.00	0.00	
IF 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00			0.00	0.00	6 1954	
1954 6	0.000	9600.000	2047.17	96756.46	130.00	130.00	0.00	Municipal Right				3840.00	0.00	0.00	
1954 6	4520.000	8360.000	0.00	0.00	3840.00	3840.00	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	9600.000	2047.17	96756.46	130.00	0.00	0.00	904.00	774.00	0.00	0.00	0.00	0.00	0.00	
CP2	4520.000	8360.000	0.00	0.00	3840.00	0.00	3840.00	1130.00	1000.00	0.00	0.00	0.00	0.00	0.00	
IF 7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00			0.00	0.00	7 1954	
1954 7	0.000	12480.000	1788.00	82488.46	0.00	0.00	0.00	Municipal Right				4992.00	0.00	0.00	
1954 7	4223.000	8360.000	0.00	0.00	4137.00	4137.00	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	12480.000	1788.00	82488.46	0.00	0.00	0.00	112.00	112.00	0.00	0.00	0.00	0.00	0.00	
CP2	4223.000	8360.000	0.00	0.00	4137.00	0.00	4992.00	145.00	1000.00	0.00	0.00	0.00	0.00	0.00	
IF 8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00			0.00	0.00	8 1954	
1954 8	0.000	11520.000	1443.60	69524.87	0.00	0.00	0.00	Municipal Right				4608.00	0.00	0.00	
1954 8	1645.000	5700.000	0.00	0.00	4055.00	4055.00	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	11520.000	1443.60	69524.87	0.00	0.00	0.00	328.00	328.00	0.00	0.00	0.00	0.00	0.00	
CP2	1645.000	5700.000	0.00	0.00	4055.00	0.00	4608.00	447.00	1000.00	0.00	0.00	0.00	0.00	0.00	
IF 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00			0.00	0.00	9 1954	
1954 9	0.000	8640.000	1217.82	59887.04	220.00	220.00	0.00	Municipal Right				3456.00	0.00	0.00	
1954 9	0.000	1900.000	0.00	0.00	1900.00	3456.00	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	8640.000	1217.82	59887.04	220.00	752.00	0.00	972.00	752.00	0.00	0.00	0.00	0.00	0.00	
CP2	0.000	1900.000	0.00	0.00	1900.00	1556.00	3456.00	1220.00	2556.00	0.00	0.00	0.00	0.00	0.00	
IF 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00			0.00	0.00	10 1954	
195410	0.000	7680.000	1051.21	53465.84	2310.00	2310.00	0.00	Municipal Right				3072.00	0.00	0.00	
195410	0.000	380.000	0.00	0.00	380.00	3072.00	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	7680.000	1051.21	53465.84	2310.00	340.00	0.00	2650.00	340.00	0.00	0.00	0.00	0.00	0.00	
CP2	0.000	380.000	0.00	0.00	380.00	2692.00	3072.00	3310.00	3692.00	0.00	0.00	0.00	0.00	0.00	
IF 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00			0.00	0.00	11 1954	
195411	0.000	7680.000	1092.58	61993.25	17300.00	17300.00	0.00	Municipal Right				3072.00	0.00	0.00	
195411	0.000	0.000	0.00	0.00	0.00	6572.00	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	7680.000	1092.58	61993.25	17300.00	0.00	0.00	17300.00	0.00	0.00	0.00	0.00	0.00	0.00	
CP2	0.000	0.000	0.00	0.00	0.00	6572.00	3072.00	21800.00	7572.00	0.00	0.00	0.00	0.00	0.00	
IF 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Instream Flow	1000.00			0.00	0.00	12 1954	
195412	0.000	5760.000	1080.67	55772.59	620.00	620.00	0.00	Municipal Right				2304.00	0.00	0.00	
195412	0.000	0.000	0.00	0.00	0.00	2304.00	0.00	Irrigation Right				0.00	0.00	0.00	
CP1	0.000	5760.000	1080.67	55772.59	620.00	670.00	0.00	1290.00	670.00	0.00	0.00	0.00	0.00	0.00	
CP2	0.000	0.000	0.00	0.00	0.00	2304.00	2304.00	1620.00	3304.00	0.00	0.00	0.00	0.00	0.00	

Table 2.9  
TABLES Output File for Example 2

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP1

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1954	66456.0	5562.3	4348.3	0.0	60893.7	55772.6	19121.1	96000.0	0.0
1955	276920.0	122536.2	122468.2	0.0	154383.8	94677.4	19478.9	96000.0	0.0
1956	113800.0	10677.5	10477.5	0.0	103122.5	83105.5	18694.4	96000.0	0.0
MEAN	152392.0	46258.7	45764.7	0.0	106133.3	77851.8	19098.2	96000.0	0.0

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP2

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1954	85382.0	36308.3	24308.3	38400.0	26580.0	0.0	0.0	26580.0	11420.0
1955	345380.0	191396.2	179396.2	38400.0	38000.0	0.0	0.0	38000.0	0.0
1956	141210.0	47699.5	35699.5	38400.0	28788.0	0.0	0.0	28788.0	9212.0
MEAN	190657.3	91801.3	79801.3	38400.0	31122.7	0.0	0.0	31122.7	6877.3

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET	MEAN	*RELIABILITY*	PERCENTAGE OF MONTHS								PERCENTAGE OF YEARS							
	DIVERSION (AC-FT/YR)	SHORTAGE (AC-FT/YR)	PERIOD (%)	VOLUME (%)	WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT								PERCENTAGE OF TARGET DIVERSION AMOUNT						
					100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%	
CP1	96000.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CP2	38000.0	6877.33	66.67	81.90	66.7	66.7	66.7	75.0	91.7	100.0	100.0	33.3	33.3	33.3	33.3	66.7	100.0	100.0	100.0
Total	134000.0	6877.33		94.87															

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	STANDARD MEAN	DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE												
			100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM	
CP1	3854.9	11960.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	147.	328.	426.	752.	11253.	64746.
CP2	7650.1	14642.5	1000.0	1000.0	1000.0	1000.0	1000.0	2168.0	3304.	3304.	3918.	6472.	17906.	80526.	

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS FOR CONTROL POINT CP2

FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)
1000.0	100.00	2000.0	77.78	5000.0	30.56	10000.0	13.89

Table 2.9 (Continued)  
TABLES Output File for Example 2

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

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
1954	110000.0	108840.0	103962.5	102843.0	108273.6	96756.5	82488.5	69524.9	59887.0	53465.8	61993.2	55772.6	84484.0
1955	52234.1	48331.5	53556.7	87992.6	110000.0	110000.0	110000.0	110000.0	110000.0	109284.4	100700.8	94677.4	91398.1
1956	90502.6	92197.9	85101.3	79235.4	110000.0	104003.3	97602.4	88227.5	78452.0	70866.9	75549.8	83105.5	87903.7
MEAN	84245.6	83123.1	80873.5	90023.7	109424.5	103586.6	96697.0	89250.8	82779.7	77872.4	79414.6	77851.8	87928.6

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1954	12700.	7660.	4760.	9190.	21400.	1130.	145.	447.	1220.	3310.	21800.	1620.	85382.
1955	4160.	3780.	15800.	51600.	78000.	96800.	21200.	26500.	31400.	11900.	1930.	2310.	345380.
1956	4090.	11200.	2140.	3210.	59300.	7160.	10060.	4950.	1380.	2320.	17100.	18300.	141210.
MEAN	6983.	7547.	7567.	21333.	52900.	35030.	10468.	10632.	11333.	5843.	13610.	7410.	190657.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1954	7390.	3424.	2218.	1000.	2152.	1000.	1000.	1000.	2556.	3692.	7572.	3304.	36308.
1955	3304.	3304.	4068.	7428.	42365.	80526.	3148.	11784.	22312.	5782.	4072.	3304.	191396.
1956	3304.	4534.	2168.	1000.	14970.	1000.	1000.	1000.	2556.	3692.	6472.	6004.	47700.
MEAN	4666.	3754.	2818.	3143.	19829.	27509.	1716.	4595.	9141.	4389.	6039.	4204.	91801.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1954	6390.	2424.	1218.	0.	1152.	0.	0.	0.	1556.	2692.	6572.	2304.	24308.
1955	2304.	2304.	3068.	6428.	41365.	79526.	2148.	10784.	21312.	4782.	3072.	2304.	179396.
1956	2304.	3534.	1168.	0.	13970.	0.	0.	0.	1556.	2692.	5472.	5004.	35700.
MEAN	3666.	2754.	1818.	2143.	18829.	26509.	716.	3595.	8141.	3389.	5039.	3204.	79801.

DIVERSIONS (AC-FT) FOR WATER RIGHT Irrigation Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1954	0.00	0.00	1520.00	3528.00	7220.00	3840.00	4137.00	4055.00	1900.00	380.00	0.00	0.00	26580.00
1955	0.00	0.00	1520.00	4560.00	7220.00	8360.00	8360.00	5700.00	1900.00	380.00	0.00	0.00	38000.00
1956	0.00	0.00	1520.00	2688.00	7220.00	4370.00	6062.00	4648.00	1900.00	380.00	0.00	0.00	28788.00
MEAN	0.00	0.00	1520.00	3592.00	7220.00	5523.33	6186.33	4801.00	1900.00	380.00	0.00	0.00	31122.67

Table 2.9 (Continued)  
TABLES Output File for Example 2

		STO	NAT	REG	UNA	IFS	DIV
		CP1	CP2	CP2	CP2	Instream	Irrigati
1954	1	110000.00	12700.00	7390.30	6390.30	0.00	0.00
1954	2	108840.00	7660.00	3424.00	2424.00	0.00	0.00
1954	3	103962.50	4760.00	2218.00	1218.00	0.00	1520.00
1954	4	102843.00	9190.00	1000.00	0.00	0.00	3528.00
1954	5	108273.60	21400.00	2152.00	1152.00	0.00	7220.00
1954	6	96756.50	1130.00	1000.00	0.00	0.00	3840.00
1954	7	82488.50	145.00	1000.00	0.00	0.00	4137.00
1954	8	69524.90	447.00	1000.00	0.00	0.00	4055.00
1954	9	59887.00	1220.00	2556.00	1556.00	0.00	1900.00
1954	10	53465.80	3310.00	3692.00	2692.00	0.00	380.00
1954	11	61993.30	21800.00	7572.00	6572.00	0.00	0.00
1954	12	55772.60	1620.00	3304.00	2304.00	0.00	0.00
1955	1	52234.10	4160.00	3304.00	2304.00	0.00	0.00
1955	2	48331.50	3780.00	3304.00	2304.00	0.00	0.00
1955	3	53556.70	15800.00	4068.00	3068.00	0.00	1520.00
1955	4	87992.60	51600.00	7428.00	6428.00	0.00	4560.00
1955	5	110000.00	78000.00	42365.20	41365.20	0.00	7220.00
1955	6	110000.00	96800.00	80525.70	79525.70	0.00	8360.00
1955	7	110000.00	21200.00	3147.60	2147.60	0.00	8360.00
1955	8	110000.00	26500.00	11783.80	10783.80	0.00	5700.00
1955	9	110000.00	31400.00	22312.00	21312.00	0.00	1900.00
1955	10	109284.40	11900.00	5782.00	4782.00	0.00	380.00
1955	11	100700.70	1930.00	4072.00	3072.00	0.00	0.00
1955	12	94677.40	2310.00	3304.00	2304.00	0.00	0.00
1956	1	90502.60	4090.00	3304.00	2304.00	0.00	0.00
1956	2	92197.90	11200.00	4534.00	3534.00	0.00	0.00
1956	3	85101.30	2140.00	2168.00	1168.00	0.00	1520.00
1956	4	79235.40	3210.00	1000.00	0.00	0.00	2688.00
1956	5	110000.00	59300.00	14969.50	13969.50	0.00	7220.00
1956	6	104003.30	7160.00	1000.00	0.00	0.00	4370.00
1956	7	97602.40	10060.00	1000.00	0.00	0.00	6062.00
1956	8	88227.50	4950.00	1000.00	0.00	0.00	4648.00
1956	9	78452.00	1380.00	2556.00	1556.00	0.00	1900.00
1956	10	70866.90	2320.00	3692.00	2692.00	0.00	380.00
1956	11	75549.80	17100.00	6472.00	5472.00	0.00	0.00
1956	12	83105.50	18300.00	6004.00	5004.00	0.00	0.00

**Measures of Water Availability and Reliability**

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

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

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

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

### Volume and Period Reliability

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

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

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

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



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

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

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

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

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

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

### Flow-Frequency and Storage-Frequency Relationships

Frequency tables created with *TABLES 2FRE* and *2FRQ* records are also included in Table 2.9. These tables may be developed for naturalized flow, regulated flow, unappropriated flow, and reservoir storage for specified control points, instream flow shortages and reservoir storage for specified water rights, and storage volume and water surface elevation for specified reservoirs. The frequency tables may be for a specified month of the year such as August or for all months. Exceedance frequency is an expression of the percentage of time that particular flow or storage amounts can be expected to occur. Equivalently, the exceedance frequency represents the likelihood or probability of a certain amount of water being available.

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

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

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

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

### **Program SIM Options Involving Cyclic Repetitions of the Simulation**

The SIM simulation computations outlined in Figure 2.2 are discussed earlier in this chapter. A specified scenario of water resources development, allocation, management, and use is simulated during each sequential month of a hydrologic period-of-analysis with stream flow inflows and reservoir net evaporation rates representing historical hydrology for natural conditions or some other specified condition of river basin development. For example, the hydrologic period-of-analysis might be 1940-2005, covering a sequence of 792 months. The simulation begins with January 1940 naturalized stream flows and net evaporation rates and proceeds through the 792 months. In many typical applications, a particular execution of SIM involves a single simulation covering the hydrologic period-of-analysis once. However, SIM has several optional features that involve two or more repetitions of the hydrologic period-of-analysis simulation automated within a single execution of SIM.

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

- Dual simulation options activated by the JO, SO or PX records and described in Chapter 4 of this *Reference Manual*.
- Yield-reliability analysis routine activated by the FY record as outlined in Chapter 6.
- Beginning-ending storage options activated by the JO record and described in Chapter 6 of this *Reference Manual*.
- Monthly cycle option of conditional reliability modeling explained in Chapter 2 of the *Supplemental Manual*.

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

The simulation is repeated in its entirety from the beginning to the end of the hydrologic period-of-analysis with the four routines noted in the preceding paragraph. Another different *SIM* modeling feature involves a second pass through the water rights priority sequence simulation repeated within individual months. Second pass options activated by instream flow *IF* record field 7 or *JO* record field 10 and outlined in Chapter 4 involve dual passes through the water right priority loop. As indicated in Figure 2.2, the two passes through the water right computations are embedded within the monthly loop.

## CHAPTER 3 HYDROLOGY FEATURES

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

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

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

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

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

## Naturalized Stream Flow

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

### Homogeneous Stream Flow Sequences

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

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

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

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

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

Other types of adjustments may be made as well. For example, land use changes such as clearing forests and urbanization or climate change due to global warming may significantly affect stream flow. A watershed model such as the *Soil and Water Assessment Tool (SWAT)* may be used to quantify the impacts of land use changes on stream flows. Wurbs, Muttiah, and Felden (2005) outline an approach for using a global circulation model reflecting climate change in combination with the *SWAT* precipitation-runoff model to adjust *WRAP* naturalized stream flows for alternative scenarios of future long-term climate change.

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

#### *WRAP Features for Developing Flow Datasets*

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

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

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

As discussed later in this chapter, program *HYD* provides various hydrology data compilation capabilities, which among other capabilities include options for:

- converting observed gaged stream flows to naturalized stream flows using techniques described later in this chapter
- distributing flows from gaged to ungaged locations using techniques described later in this chapter
- otherwise adjusting stream flows as described in Chapter 6

*HYD* writes stream flows as a set of inflow *IN* records in a text file or as binary records in a Data Storage System (DSS) file for input to *SIM*.

## Reservoir Evaporation-Precipitation

Evaporation from a reservoir and precipitation falling directly on the reservoir water surface are combined as a net evaporation minus precipitation. Net evaporation less precipitation volumes are computed by multiplying the reservoir water surface area by net evaporation-precipitation rates provided on *EV* records in dimensions of depth/month. Various units may be used. Typical units include water surface area in acres, evaporation-precipitation rates in feet/month, and volumetric rates in acre-feet/month. Computation of evaporation-precipitation volumes are incorporated in *HYD* and *SIM* reservoir volume accounting routines. The *SIM* evaporation computations are described in the Chapter 5 section entitled *Iterative Reservoir Volume Balance Computations*.

Within *HYD*, the computations are performed in conjunction with reservoir adjustments for converting gaged stream flow to naturalized stream flow. *HYD* also provides optional capabilities for combining sets of evaporation and/or precipitation depths to develop *EV* records. Precipitation depths may be subtracted from evaporation depths or sets of evaporation, precipitation, or net evaporation-precipitation depths may be averaged.

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

### Adjusted Net Evaporation-Precipitation

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

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

The procedure in *SIM* for adjusting net evaporation-precipitation depths for runoff from reservoir sites are outlined as follows. The *HYD* version is outlined later in this chapter.

- Net evaporation minus precipitation depths are input on *EV* records in an EVA file or as binary records in a DSS file.
- A precipitation-runoff adjustment term is computed within *SIM* to prevent *double-counting* the reservoir surface precipitation that is already in the *IN* record naturalized flows. *JD* record field 10 (*EPADJ*) and *CP* record field 9 (*EWA*) activates this option. The *JD* record field 10 sets the default option applied to all control points for which the *CP* record field 9 is left blank. An entry for *EWA* on a *CP* record overrides the default option set by *EPADJ* on the *JD* record. Without the *JD* and *CP* record entries, the adjustment option is not applied.
- The precipitation-runoff adjustment requires a drainage area and corresponding naturalized stream flows. An effective total watershed area may be input as a positive number in *CP* record field 9 for use with the total naturalized flows at that control point. Alternatively, the incremental or total watershed area and corresponding incremental or total naturalized flows for either the ungaged (*FD* record field 2) or gaged (*FD* record field 3) control points may be used by entering a  $-1$  or  $-2$  in *CP* record field 9 (applicable to that control point) or *JD* record field 10 (default for all control points). Incremental flows and watershed areas determined based on information from the *FD* and *WP* records are identically the same for the rainfall-runoff adjustments as for distributing stream flows from gaged to ungaged sites.

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

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

### **Program HYD Hydrology Data Manipulation Capabilities**

Program *HYD* is designed to facilitate developing hydrology-related input data for *SIM*. The *HYD*rology data program provides a set of optional routines to read, modify, and create sequences of naturalized or otherwise adjusted monthly stream flow volumes and net reservoir surface monthly evaporation less precipitation depths. *HYD* output files are read by *SIM* as input files. *HYD* has certain computational routines that are also available in *SIM* and others that are not.



Data may be simply read from *HYD* input files and written to a *HYD* output file with no adjustments other than changing the organization and/or format of the dataset. Alternatively, the data may undergo a variety of adjustments and manipulations employing various computational options. Capabilities are provided for performing the tasks outlined in Table 3.1 and discussed in the following paragraphs. The tasks are listed in Table 3.1 generally in the order in which they are performed within *HYD*. All tasks are optional. The model-user specifies any number of tasks to be performed in a particular execution of *HYD* through entries on the *JC*, *CP*, *EP*, *OI*, *AN*, *AS*, *RS* and *EQ* input records which are described in Chapter 5 of the *Users Manual*.

The various *HYD* options involve reading data from *HYD* input files or a *SIM* output file and performing computations to create stream flow and/or evaporation-precipitation datasets stored in new files. *HYD* options also include developing several related tables as well as sets of *IN* and *EV* records or DSS records. A single execution of *HYD* may include any number of data adjustments. Alternatively, in order to sequence the adjustments certain ways, multiple runs may be made with the output file from one run being read as the input file for the next. Files may also be transported back and forth between *HYD* and spreadsheet programs. Many of the computations performed by *HYD* are also adaptable to spreadsheet programs.

### Initial Data Manipulations

The following optional initial tasks are activated by parameters entered on *XL*, *CP*, and *MF* records described in Chapter 5 of the *Users Manual*.

- The flows and/or evaporation-precipitation rates are multiplied by factors specified on *XL*, *CP*, and *MF* records. The monthly factors on *MF* records may also be added.
- Stream flows and/or evaporation-precipitation rates may be assigned to a control point by either verbatim repeating data from another control point or by multiplying the repeated flows by the factors from the *CP* records.

The *XL* and *CP* record factors in *HYD* are essentially the same as the factors in *SIM* covered in Chapter 3 of the *Users Manual*. The factors may be used for unit conversions, such as converting stream flows from second-feet-day ( $\text{ft}^3/\text{s}\times\text{day}$ ) to acre-feet or net evaporation-precipitation depths from inches to feet. Also, the same stream flow or evaporation-precipitation rates may be conveniently assigned to multiple control points as appropriate. Drainage area ratios may be applied to transfer flows from gaged to ungaged sites. These data adjustments occurring immediately after the original data are read are then followed by the other optional tasks listed in Table 3.1.

### Changing the Organization and Format of the Datasets

*HYD* reads input files near the beginning of program execution before the data handling and computational tasks and writes to output files near the end. The organization and format for the output files may be different than that of the input files. Datasets may also be converted between text files and Data Storage System (DSS) files and between *SIM/HYD* files and Microsoft Excel spreadsheet files. Text files may be reorganized. Options listed in Table 3.1 allow reading input files in alternative formats and converting to another selected format. The alternative formats are further discussed in Chapter 5 of the *Users Manual*.

Table 3.1  
Capabilities Provided by Program HYD

---

Initial Manipulations of Stream Flows and Evaporation-Precipitation Depths

- Multiplying the original data by constants specified on *XL* or *CP* records or multiplying or adding monthly-varying factors from *MF* records.
- Assigning flows or net evaporation-precipitation rates to a control point by either verbatim repeating data from another control point or by multiplying the repeated flows by the factors from the *CP* records.

Annual Set of Monthly Flow Volumes or Evaporation-Precipitation Depths

- Sets of 12 monthly volumes or depths for each control point may determined by alternative methods including means or assigning a specified exceedance frequency.

Developing Sets of Net Evaporation-Precipitation Depths (EV Records)

- Subtracting precipitation depths from evaporation depths to obtain net evaporation-precipitation depths.
- Developing net evaporation-precipitation depths for a particular control point as a weighted average of values from two, three, or four other data sets.
- Adjusting evaporation-precipitation depths (E) using the equation:  $E_{\text{adjusted}} = a E^b + c$

Developing Sets of Naturalized or Otherwise Adjusted Stream Flows (IN Records)

- Adding or subtracting sets of adjustments to stream flows associated with historical water supply diversions and return flows, reservoir storage and evaporation, and other factors that may be pertinent.
- Developing adjustments for the historical effects of reservoir storage and net evaporation-precipitation.
- Applying the equations:  $Q_{\text{adjusted}} = a Q^b + c$  or  $\Delta Q_{\text{adjustment}} = (a Q^b + c) - Q$
- Distributing flows from gaged (known flow) to ungaged (unknown flow) locations.
- Adjusting stream flows to prevent incremental flows from being negative.

Changing the Organization and Format of the Datasets

- Converting the format of the FLO and EVA files between records grouped by control points versus records grouped by year.
  - Converting an HYD file to FLO and EVA files in the standard format or vice versa.
  - Converting between FLO and EVA text files and DSS binary files.
  - Converting flows and evaporation-precipitation depths to a columnar format, and vice versa, to interchange with Microsoft Excel or other programs.
  - Converting *SIM* simulation results to *SIM/HYD* input record format.
-

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

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

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

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

Typical applications of this feature include:

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

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

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

The monthly stream flows (*Q*) and evaporation-precipitation depths (*E*) at a control point may be adjusted by applying the equations:

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

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

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

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

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

The regression equation feature may be used in various ways. It was incorporated into *HYD* particularly for use with a precipitation-runoff watershed simulation model such as the *Soil and Water Assessment Tool (SWAT)* developed at the USDA Agricultural Research Service and Texas Agricultural Experiment Station Research Center in Temple, Texas. The precipitation-runoff model may be used to quantify the effects of watershed land use changes. *SWAT* and *WRAP* have also been applied in combination on a research project assessing the impacts of climate change on water management (Wurbs et al. 2005). Stream flow is computed with *SWAT* for given precipitation and other climatic data and watershed characteristics. Changes in land use are modeled by changing watershed parameter values. Changes in climate are reflected in precipitation, temperature, and other climatic variables. The precipitation-runoff model is applied to compute stream flows for scenarios with and without climate or watershed changes. Regression analyses are then applied to flows computed with the two different scenarios to obtain a set of  $a$ ,  $b$ ,  $c$  coefficients for input to *WRAP-HYD*. As discussed later in this chapter, a regression equation likewise may be used with *FD/FC* records to distribute flows from gaged to ungaged locations.

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

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

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

The objective of the stream flow adjustment routines in *HYD* is to provide a flexible generic set of options to facilitate adjusting a set of stream flows to reflect changes in river basin development. The most typical application is converting historical stream flows to naturalized flows. However, conversions between other scenarios of watershed development may also be of interest. *HYD* is designed to be flexible for application to various situations including those discussed in Chapter 6 as well as the type of applications noted in the present Chapter 3. Manipulation of flow data may involve combined use of *HYD*, Microsoft Excel or other spreadsheet programs, and HEC-DSSVue.

#### **Stream Flow Naturalization Adjustments**

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

example, changes in spring flows or stream base flows determined with a groundwater model and associated with alternative aquifer management strategies may be treated as adjustments to naturalized stream flows.

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

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

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

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

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

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

### Stream Flow Adjustments for the Effects of Reservoirs

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

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

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

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

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

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

*JC* record field 17 (*EPADJ*), *CP* record field 9 (*EWA*), and *RS* record field 7 (*RS(5)*) activate this *HYD* option. *RS(5)* specifies whether the site runoff is included in a particular reservoir adjustment. *JC* field 12 sets the default option applied to all control points for which the *CP* field 9 is left blank. An entry for *EWA* on a *CP* record overrides the default option set by *EPADJ* on the *JC* record. The precipitation-runoff adjustment requires a drainage area. An effective total watershed area may be input as a positive number in *CP* field 9 for use with the total naturalized flows at that control point. Alternatively, the incremental or total watershed area and corresponding incremental or total flows for either the ungaged (*FD* record field 2) or gaged (*FD* field 3) control points may be used by entering a -1 or -2 in *CP* field 9 (for that control point) or *JC* field 17 (default for all control points). Incremental flows and watershed areas determined based on information from the *FD* and *WP* records are identically the same for the rainfall-runoff adjustments as for distributing flows from gaged to ungaged sites.

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

### Distributing Flows from Gaged to Ungaged Locations

Naturalized flows are typically developed for locations of gaging stations by adjusting the recorded observed flows. Naturalized flows at numerous ungaged sites of water rights are then estimated based on combining the concurrent naturalized flows at gaging stations with parameters characterizing the watersheds above the gaged and ungaged sites. Alternative methods for transferring naturalized flows from gaged (known flow) to ungaged (unknown flow) locations are outlined in detail later in this chapter. These techniques include the drainage area ratio method, a modified version of the NRCS curve number methodology, and other related approaches. Watershed parameters are entered on *FD*, *FC*, and *WP* records in a DIS file. *HYD* includes an

option for developing tables displaying the watershed parameters including both values inputted on *WP* records and values for incremental watersheds computed within *HYD*.

The same flow distribution techniques are incorporated in both *HYD* and *SIM*, but the computed flows are stored in different formats. *HYD* stores the flows computed for the ungaged control points as *IN* records along with the original *IN* records for the known-flow control points. *SIM* writes synthesized naturalized flows to its output file just like all the other simulation results. In a typical major river basin application, recorded flows may be used from perhaps 10 to 25 gaging stations. Naturalized flows developed at the gage sites may then be distributed to several other key control points (perhaps another 10-25 sites) within *HYD* with the results permanently stored as *IN* records in the *HYD* output (*SIM* input) file. Within *SIM*, naturalized flows may be distributed to several hundred other sites internally without further enlarging the file of *IN* records.

### Negative Incremental Stream Flow Adjustments

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

Options for dealing with negative incremental flows are outlined in the last section of this chapter. Negative incremental inflow options 1, 2, 3, and 4 specified on the *HYD JC* record or *SIM JD* record are the same in either program. *HYD* adjusts the *IN* records for options 2, 3, and 4. Options 3 and 4 involve the same flow adjustments applied in a different manner. Option 5 involves computations performed within the *SIM* water rights loop that are not pertinent to *HYD*.

### Allocation of Stream Flow within SIM

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

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



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

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

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

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

### **Channel Losses**

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

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

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

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

By definition, the channel loss coefficient  $F_{CL}$  should range from 0.0 to 1.0.  $F_{CL}$  for the river reach below a control point is input as variable  $CL$  in field 10 of the control point  $CP$  record. All control points are internally assigned a default  $CL$  of zero, with the user providing the  $CL$  on the  $CP$  records for any control points with non-zero values. As discussed below, this linear stream flow versus loss relationship and  $CP$  record loss factor is incorporated in several routines in programs *SIM* and *HYD*.

#### Channel Losses in WRAP-SIM

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

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

Both channel loss credits and channel losses are computed and written to the output file within the *SIM* water rights and period loops. The total of the channel loss credits for each month at each control point are written in the control point output record. Likewise, the total monthly channel losses are written in field 12 of the control point records in the *SIM* output file. Program *TABLES* reads the *SIM* output file and builds user-specified tables which may include

the channel losses and credits. The difference between the credits tabulated by a *2CLC* record and losses tabulated by a *2CLO* record is as follows.

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

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

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

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

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

The channel loss credit computations for adjustments to regulated and unappropriated flows associated with stream flow depletions for diversion and storage rights are described below. Similar algorithms compute channel losses associated with return flows and releases

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

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

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

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

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

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

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

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

### Channel Losses in WRAP-HYD

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

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

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

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

The stream flow at the  $N$ th control point below the diversion, reservoir, or other adjustment is adjusted as follows, where  $C_{L1}, C_{L2}, C_{L3}, \dots, C_{LN}$  denote the channel loss coefficients for each of the  $N$  individual reaches between the control point at which the flow adjustment  $A_F$  occurs and the control point at which the stream flow  $F_{\text{adjusted}}$  is being adjusted.

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

### **Methods for Establishing Stream Flow Inflows**

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

The input variable *INMETHOD(cp)* on the *SIM* control point *CP* record controls selection of the options listed in Table 3.2 for assigning naturalized flows to each control point. Option 1 consists of providing flows in a *SIM* input file for a control point, which is called a primary control point. Options 2 through 8 involve distributing flows from a primary control point to a secondary control point. The same *INMETHOD(cp)* options 1 through 8 are also selected on the *HYD* control point *CP* record. Inflow options 1 and 2 and the flow distribution methods (options 3-8) are the same in *HYD* and *SIM*. Option 9 is applicable only to *SIM*.

Table 3.2  
Methods for Establishing Stream Flow Inflows

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

The *CP* record field 4 default option 1 listed in Table 3.2 consists of providing flows for the control point as input for either *SIM* or *HYD*, which may be in the form of inflow *IN* records in a text file (FLO, DAT, HYD files) or as binary records a DSS file. At least one *SIM* control point must be assigned flows based on option 1. The term *SIM primary control point* is applied to control points for which flows are provided as input. *Secondary control points* have flows computed within *SIM* based on flows at primary control points provided in a *SIM* input file.

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

Option 9 applicable only to *SIM* allows a control point to be included in the input dataset without being assigned stream flows. In most typical applications, there is no need for including control points in the model without assigning stream flows. Water rights and reservoirs are assigned to appropriate control point locations that define the stream flow available to them. However, option 9 is available for unusual situations in which control points are included in a model without stream flows being assigned. Option 9 is very different than assigning zero values for stream flows.

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

### **Distribution of Naturalized Flows from Gaged to Ungaged Control Points**

The term *flow distribution* refers to the computation within *SIM* or *HYD* of naturalized stream flows at a control point based upon known naturalized flows at one or more other control points. As discussed in the preceding section, *SIM* and *HYD* control point *CP* record field 4 controls the specification of method for assigning flows. The alternative methods for distributing naturalized flows from gaged (known-flow) to ungaged (unknown-flow) control points are listed as options 3 through 8 in Table 3.2. Input parameters are provided on flow distribution *FD*, flow distribution coefficients *FC*, and watershed parameter *WP* records stored in a DIS file.

The flow distribution computations are the same in *HYD* and *SIM*, but the computed flows are output in a different format. *HYD* provides capabilities for developing *SIM* hydrology datasets (*IN* and *EV* records in text files or binary records in a DSS file) for specified control

points from given inflow *IN* and evaporation rate *EV* records at other control points. The synthesized flows are output along with the known flows. Conversely, if naturalized flows are synthesized within *SIM*, the inputted and computed naturalized flows are output to the *SIM* output file and read by *TABLES* just like all the other simulation output.

Stream flows may be distributed from gaged (known-flow) to ungaged (unknown-flow) control points within either programs *HYD* or *SIM* using the same methodologies. The computations are the same, but the computed flows are output in a different format. *HYD* provides capabilities for developing *SIM* hydrology (*IN* and *EV* record) files at specified control points from given inflow *IN* and evaporation rate *EV* records at other control points. The synthesized flows are output on *IN* records along with the known flows. Conversely, if naturalized flows are synthesized within *SIM*, the inputted and computed naturalized flows are output to the *SIM* output file and read by *TABLES* just like all the other simulation output.

### Incremental Watersheds

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

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

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

The schematic and equations shown in Figure 3.1 illustrate the scheme by which *HYD* and *SIM* allow the user to define incremental watersheds on *FD* records for use in distributing flows. Figure 3.1 also serves as the schematic for an example in Appendix J that demonstrates flow distribution features. In Figure 3.1, flows are known at gaged control points (CPs) J, K, L,

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

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

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

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

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

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

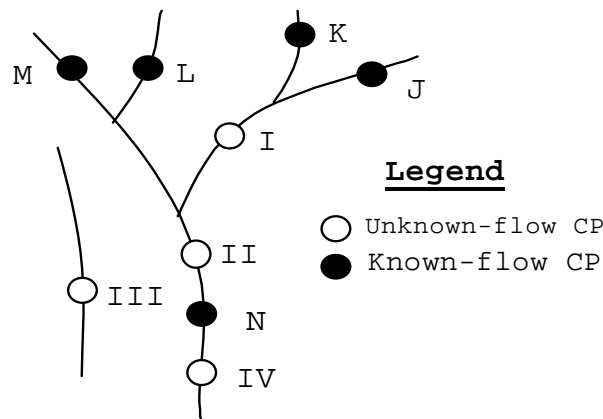


Figure 3.1 Gaged (Known-Flow) and Ungaged (Unknown-Flow) Control Points

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



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

- control point identifier of ungaged (unknown-flow) control point to which flows are being distributed
- control point identifier of gaged (known-flow) control point from which flows are being distributed
- control point identifiers of the upstream control points used to compute incremental flows
- the number of upstream control points used to compute the incremental flows at the ungaged (unknown-flow) control point

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

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

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

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

### Flow Distribution Methods

Methods for distributing naturalized stream flows from gaged or known-flow locations to ungaged sites are explored by Wurbs and Sisson (1999). The same flow synthesis methods in both *HYD* and *SIM* are activated by *CP* record field 4 and are based on parameters provided on *FD*, *FC*, and *WP* records in a DIS file. The flow distribution methods may be applied to either

incremental or total flows as defined by *FD* records. These methods listed as options 3 through 8 in Table 3.2 are based on either:

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

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

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

- an adaptation of the NRCS curve number method with values for the watershed parameters provided on *WP* records. If the watershed parameters (curve number and mean precipitation) are the same for both the gaged and ungaged watershed (or left blank on *WP* record), the modified NRCS CN method also reduces to the drainage area ratio method.

- the following equation which incorporates a channel loss coefficient  $F_{CL}$  into the drainage area ratio ( $R_{DA}$ ) method.

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

### Generalized Regression Equation (Option 3)

Option 3 listed in Table 3.2 consists of distributing flows using Equation 3.10 with the coefficients  $a$ ,  $b$ , and  $c$  input on a *FC* record.

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

Various methodologies may be devised for developing the input parameters  $a$ ,  $b$ , and  $c$ . For example, Wurbs and Sisson (1999) describe an approach for developing the coefficients from a regression analysis of the results of a watershed precipitation-runoff model.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

where  $Q$  denotes runoff volume-equivalent in inches,  $P$  is precipitation depth in inches,  $S$  is the maximum potential retention, and  $CN$  is the curve number (NRCS 1985).  $S$  represents the losses that would occur after initial abstractions are satisfied given unlimited rainfall.  $S$  is related to the watershed parameter  $CN$  which varies with soil type, land use, and antecedent precipitation.

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

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

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

where  $M_{\text{ungaged}}$  and  $M_{\text{gage}}$  are the mean precipitation for the unaged subwatershed and gaged watershed. Otherwise,  $P_{\text{ungaged}}$  is assumed equal to  $P_{\text{gage}}$ .

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

#### Unit Conversion for NRCS CN Equation

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

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

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

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

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

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

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

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

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

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

The *SIM* and *HYD* subroutine *FLDIST* distributes flows from gaged to ungaged locations for options 3 through 8 listed in Table 3.2. Subroutine *IACNP* reads the *FD* and *WP* records from the *DIS* file and computes incremental drainage areas (A), curve numbers (CN), and mean precipitation (MP) for use in subroutine *FLDIST*. The CN and MP for an incremental watershed are computed from the CN's and MP's read from the *WP* records for total watersheds. The basic premise in computing the CN and MP for an incremental watershed is that the CN or MP for a total watershed equals the area-weighted average of the values for all its subwatersheds.

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

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

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

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

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

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

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

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

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

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

### Ungaged Control Point Located Upstream of Source Gaged Control Point

Options 6 and 8 in Table 3.2 are designed to be applied specifically and only for the situation in which the ungaged control point is located upstream of the source gaged site with channel losses occurring in between. This situation is complicated by the fact that the flow at the ungaged site is a function of the flow at the gaged site  $Q_{\text{gaged}}$  plus channel losses  $F_{\text{CL}}Q_{\text{ungaged}}$

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

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

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

$$Q_{\text{II}} = f(Q_{\text{N}} + F_{\text{CL}}Q_{\text{II}})$$

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

$$Q_{\text{II}} = R_{\text{DA}} (Q_{\text{N}} + F_{\text{CL}}Q_{\text{II}})$$

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

$$\text{Equivalent } (1.0 - F_{\text{CL}}) = (1.0 - F_{\text{CL}1}) (1.0 - F_{\text{CL}2}) (1.0 - F_{\text{CL}3}) \dots (1.0 - F_{\text{CL}N}) \quad (3.19)$$

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

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

Options 6 and 8 incorporating the channel loss factor ( $F_{\text{CL}}$ ) are applicable if the channel losses in the reach between the ungaged and gaged control point are significantly greater than in the other streams in the watershed and thus not adequately reflected in the flow proportioning of the CN

and drainage area ratio methods without the  $F_{CL}$ . Incorporating a  $F_{CL}$  results in higher estimates of the flow amounts at the ungaged control point.

Option 6 - Drainage Area Ratio with Channel Losses

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

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

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

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

*INMETHOD(cp)* option 6 in Table 3.2 consists of applying Equation 3.11. The model obtains  $F_{CL}$  from the *CP* record for the ungaged control point and the watershed areas from the appropriate *WP* records. For multiple intermediate control points between the gaged and ungaged sites, an equivalent  $F_{CL}$  is determined as previously noted. Option 6 is applicable only in situations where the ungaged control point is located upstream of the gaged control point and the channel losses between the control points are greater than otherwise reflected in the simple drainage area ratio method of Equation 3.9.

Option 8 - NRCS CN Method with Channel Losses

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

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

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

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



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

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

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

WARNING: Convergence criterion of 0.5% was not met for flow distribution option 8 after 100 iterations at ungaged CP \_\_\_\_\_ for year \_\_\_\_\_, month \_\_\_\_\_. Last flow computed of \_\_\_\_\_ was adopted.

#### Multipliers and Control Point Identifiers on CP Record (Option 2)

*HYD* and *SIM* CP records include the variables  $CPIN(cp)$  and  $CPEV(cp)$  which specify other control points with flows or net evaporation-precipitation rates, respectively, which are to be used for control point  $cp$ . Thus, the flow at another control point can be used without change or multiplied by  $CPDT(cp,1)$ . The approach is referred to as option 2 in Table 3.2. Also, zero flows can be specified on the CP record.

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

#### Watershed Flow Option

*WRAP-SIM* includes an alternative simplified option for dealing with water right diversions and storage at many remote ungaged locations throughout the watersheds above the control points. The watershed flow option supplements the control point network in delineating the location of water rights. All rights are assigned a control point and, in the model computations, affect unappropriated flows and water availability at that control point and downstream control points. Multiple rights may be assigned to the same control point. The watershed flow option is used for rights at locations in the watersheds above their assigned control points. The site in the watershed at

which the right is actually located has no *CP* record and is not treated as a control point. *WRAP-SIM* limits water available to each of these rights to the lesser of:

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

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

### **Use of GIS to Determine Spatial Connectivity and Watershed Parameters**

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

In developing the WRAP input datasets for the river basins of Texas for the TCEQ WAM System described in Chapter 1, a GIS methodology based on the ESRI software products ArcView and ArcInfo was developed and applied to determine spatial connectivity and estimate values for watershed parameters (Hudgens and Maidment 1999; Mason and Maidment 2000; Figurski and Maidment 2001). Later improvements in the ESRI ArcGIS software include expanded Arc Hydro capabilities for developing river basin data (Maidment 2002). Gopalan (2003) describes Arc Hydro procedures adopted specifically for developing watershed parameters for input to WRAP.

In a WRAP model of a river basin, every control point except the basin outlet has another control point located immediately downstream. The control point *CP* record for each control point includes an entry for the identifier of the next downstream control point. The computational routines within WRAP use the next downstream control point designated for each control point to define spatial connectivity. For river basins with hundreds of control points, a GIS is very useful for developing a list of the next downstream control point associated with each control point.

Watershed drainage areas are required for all of the methods for distributing naturalized flows from gaged to ungaged sites. The curve number CN and mean precipitation MP are also required if the NRCS CN method adaptation is used for distributing flows. The following datasets were used to develop these watershed parameters for the Texas WAM System.

- digital elevation models of land surface terrain available from the U.S. Geological Survey
- set of USGS stream gaging station locations
- stream network available from the U.S. Environmental Protection Agency
- set of water right locations developed by TCEQ and consulting firms
- grid of mean annual precipitation from the PRISM project developed at Oregon State University for the USDA Natural Resource Conservation Service
- grid of curve numbers developed by the TAES Blackland Research Center for the HUMUS Project sponsored by the USDA NRCS

The curve number (CN) database was previously produced by the Texas Agricultural Experiment Station of the Texas A&M University System for the Hydrologic Unit Modeling of the United States (HUMUS) project sponsored by the USDA Natural Resource Conservation Service (NRCS). The CN grid was developed by intersecting maps of land use and soil type and combining the results with a CN table to determine the CN for each grid cell.

### **Negative Incremental Naturalized Stream Flows**

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

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

#### **Example 3 - Negative Incremental Stream flows**

An example is provided in Figure 3.2 and Tables 3.3 and 3.4. Naturalized flows at each control point for a particular month are tabulated in column 2 of Table 3.3 and also shown in the figure. The incremental inflows between each control point and its adjacent upstream control points are shown in column 3. Incremental flows are negative at control point CP-2 (incremental flow =  $81 - 90 = -9$ ) and control point 6 (incremental flow =  $80 - 100 - 8 = -28$ ). As illustrated by columns 4 and 6 of Table 3.3 and discussed later, negative incremental flows alternatively may be defined considering all control points located either upstream or downstream of a particular control point. As illustrated by columns 5 and 7 and also discussed later, negative incremental flows may be eliminated by adjusting the flows at pertinent control points.

#### **Significance of Negative Incremental Naturalized Stream Flows**

The amount of water available to a water right and the unappropriated stream flow at a control point may be affected by the magnitude of the naturalized stream flows at that control point and all downstream control points. The relevance of flows being smaller downstream than upstream (negative incremental) and associated adjustments are related to the effects on the amount

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

Negative incremental flows are of concern primarily because downstream flow conditions affect the amount of water available at upstream locations in the *WRAP-SIM* simulation computations. Referring to Figure 3.2 and column 4 (Option 1: no adjustments) of Table 3.4, the amount of stream flow initially available at control point CP-1 is the lesser of the total stream flows at CP-1 (90 ac-ft), CP-2 (81 ac-ft), CP-4 (100 ac-ft), or CP-6 (80 ac-ft). Thus, the available flow at CP-1 is 80 ac-ft, which is governed by the CP-6 flow that reflects negative incremental flow. The available flow at CP-4 is 80 ac-ft. As the water rights computational loop progresses, the amount of water availability to rights at each control point may be further reduced by senior rights.

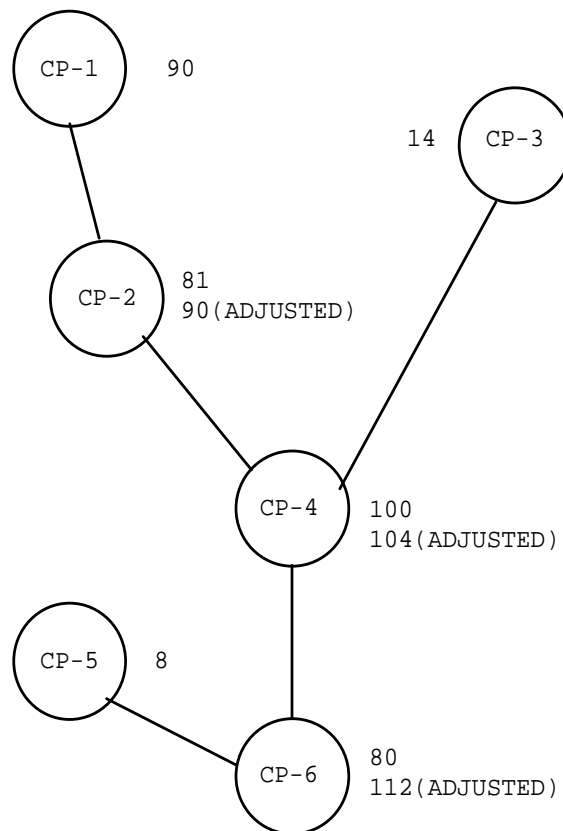


Figure 3.2 System with Negative Incremental Inflows

Table 3.3  
Incremental Naturalized Stream flow Example

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

Table 3.4  
Available Stream flows for the Example

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

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

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

*HYD* and *SIM* provide optional capabilities for handling the issue of negative incremental inflows. Both programs provide options to write two alternative forms of negative incremental flow data to a file for information. This file facilitates examination of the frequency, magnitude, and location of negative incremental inflows. Both programs also contain routines for adjusting stream flows to remove negative incrementals. *HYD* is limited to creating an adjusted set of *IN* records. *SIM* computes the same adjustments but provides greater flexibility for applying adjustments during the course of the simulation.

### Channel Losses

As previously discussed, a channel loss factor  $CL(cp)$  entered in field 10 of the *CP* record is defined by Equation 3.3.  $CL(cp)$  is used in the various channel loss computations that occur throughout the simulation. Conceptually, if the negative incremental flows are due strictly to channel losses, and the linear channel loss equation accurately models channel losses, negative incrementals are handled automatically within *SIM* and are not a concern. Of course, in reality, negative incrementals can not be perfectly explained with a simple linear relationship between channel loss and upstream flow. However, the channel loss routine incorporated in determining the amount of water available for a right may significantly reduce or mitigate the effects of negative incremental flows.

In the example, if  $CL(cp)$  for control points CP-1 and CP-4 are 0.1 and 0.2, respectively, or greater, the negative incremental flows do not constrain water availability at upstream locations at the beginning of the simulation. In the example, the amount of water available at control point CP-1 for the first water right is 90 ac-ft as shown in column 3 of Table 3.4. The 90 ac-ft at CP-1 is determined as the minimum of the following values.

$$CP-1: 90$$

$$CP-2: 90 = 81 / (1.0 - CL(I)) = 81 / (1.0 - 0.1)$$

$$CP-4: 111 = 100 / [1.0(1.0 - CL(I))] = 100 / [1.0(1.0 - 0.1)]$$

$$CP-6: 111 = 80 / [(1.0 - CL(4))(1.0)(1.0 - CL(I))] = 80 / [(1.0 - 0.2)(1.0)(1.0 - 0.1)]$$

The 100 ac-ft of available stream flow at control point 4 is determined as the minimum of:

$$CP-4: 100$$

$$CP-6: 100 = 80 / (1.0 - CL(4)) = 80 / (1.0 - 0.2)$$

### Downstream and Upstream Negative Incremental Flow Adjustments

*HYD* and *SIM* negative incremental flow adjustment options are based on two alternative ways of defining negative incremental flow adjustments, referred to as *downstream* versus *upstream*

incrementals. The approach for computing the *downstream* incremental flow adjustments associated with a particular control point compares its flow to the flow at each control point located downstream. Negative incremental flows between a control point and its downstream control points are shown in column 4 of Table 3.3. The negative incremental inflow is the greatest difference between the naturalized stream flow at the control point and any control point located downstream. The negative incremental flow is written as either zero or a negative number indicating the amount that must be subtracted from the flow at that control point to equal the lowest flow occurring at any downstream control point. These downstream negative incremental flow adjustments are added to the naturalized flows in column 2 to obtain the adjusted flows in column 5 of Table 3.3.

Upstream negative incremental flow adjustments associated with a control point represent the amount that must be added to the flow at that control point to remove all negative incremental flows occurring at all control points located upstream. This form of negative incremental flow is written to the *HYD* OUT or *SIM* MSS files as either zero or positive, indicating an amount the stream flow at the control point must be increased to alleviate negative incrementals. Upstream negative incremental flow adjustments for the example are shown in column 6 of Table 3.3. These adjustments are added to the naturalized flows to obtain the adjusted flows in column 7.

#### Writing Negative Incremental Inflow Adjustments to a File

Both *HYD* and *SIM* include options, specified by variable *NEGINC* on the *JC* or *JD* record, to write the two alternative forms (downstream versus upstream illustrated by columns 4 and 6 of Table 3.3) of negative incremental inflow adjustments to a file for information. The model user may examine this file to determine the extent of negative incrementals in the naturalized stream flow data set (*IN* records). Both programs output these data in the same format to the message file (*SIM*) or output file (*HYD*).

#### Options for Adjusting Naturalized Stream Flows

Both *HYD* and *SIM* include options, specified by variable *ADJINC* on the *JC* or *JD* record, to adjust naturalized stream flows to remove negative incrementals. Options 1, 2, 3 defined below are relevant to either *HYD* or *SIM*. Options 4 and 5 are relevant only to *SIM*. *HYD* reads a set of *IN* records from a root1.INF file, illustrated by the flows of column 2, and creates a set of *IN* records with adjusted flows as illustrated by columns 5 and 7 of Table 3.3. The resulting output file (filename root2.INF) is read as an input file by *SIM*. *SIM* makes these same adjustments to the naturalized flows without rewriting the *IN* records. Options 4 and 5 described below include computations made within the *SIM* water rights simulation loop and thus is not available in *HYD*.

Negative incremental flow adjustment options are selected using variable *ADJINC* on the *JD* or *JC* record. The alternative negative incremental flow adjustment options are outlined as follows.

- Option 1:* No negative incremental flow adjustments. (*ADJINC* = 0 or 1)
- Option 2:* Downstream negative incremental flow adjustments. (*ADJINC* = 2)
- Option 3:* Upstream negative incremental flow adjustments are applied at all control points. (*ADJINC* = 3)

- Option -3:* Variation of Option 3 in which control points with synthesized flows are omitted. Otherwise, Options -3 and 3 are the same. ( $ADJINC = -3$ )
- Option 4:* As each water right is considered, upstream negative incremental flow adjustments are applied at the downstream control points but not at the control point of the right. ( $ADJINC = 4$ )
- Option -4:* Variation of Option 4 in which control points with synthesized flows are omitted. Otherwise, Options -4 and 4 are the same. ( $ADJINC = -4$ )
- Option 5:* A different approach involving modifications to the computations within the water rights loop. Whereas Options 2, 3, and 4 involve computation of an array of flow adjustments, Option 5 does not.

With  $ADJINC = 1, 2, 3, 4,$  or  $5$ , all control points are treated the same regardless of source of naturalized stream flows.  $ADJINC = -3$  and  $-4$  activate variations of Options 3 and 4 in which incremental flows are defined in terms of only those control points for which  $INMETHOD$  in field 6 of the  $CP$  record is 0, 1, or 2. This includes the control points for which  $IN$  records are entered and those for which flows are transferred using Option 2. Control points for which flow distribution methods 3, 4, 5, 6, 7, and 8 are applied to determine naturalized flows are excluded in defining incremental flows or applying negative incremental flow adjustments.

The amount of naturalized stream flow available for the most senior right in Example 3 is shown in Table 3.4 for each of Options 1–4. The available flows for Option 1 without and with the channel loss option are tabulated in columns 3 and 4, respectively. The available flows in column 3 are based on combining the default (option 1) no incremental flow adjustments with the channel loss option with loss factors  $CL(cp)$  of 0.1 and 0.2 for control points CP-1 and CP-4, respectively. Although not shown in the table, combining the channel loss factors  $CL(1)=0.1$  and  $CL(4)=0.2$  with Option 4 results in the same available flows shown in both columns 3 and 7. Option 2 consists of adding the adjustments from column 4 of Figure 3.1 to obtain the available stream flow shown in column 5 of Table 3.4. Options 3 and 4 both involve computation of the flow adjustments in column 6 of Table 3.3, but the adjustments are applied differently with Option 4 than with Option 3.

**Option 1** consists of making no adjustments for negative incremental flows. This is more conservative than Options 3 and 4 from the perspective of placing maximum restrictions on the amount of stream flow available to the water rights. In some cases, this may be the most accurate option. In other cases, it may be overly conservative from the perspective of restricting water availability too much, inappropriately increasing diversion shortages and lowering reservoir storage and unappropriated flows. As previously discussed, use of the channel loss option will reduce or eliminate the restrictions on water availability associated with negative incremental flows. If the negative incremental flows are due primarily to channel losses and reasonably good values for  $CL(cp)$  are available, this is more likely to be the best option.

**Option 2** is based on downstream negative incremental flow adjustments. Since control points on multiple tributaries are not considered concurrently, there is no guarantee of eliminating all negative incrementals. Options 1 and/or 4 will typically be better than Option 2. Reducing naturalized stream flows by the downstream incremental flow adjustments (Option 2) provides few if any advantages relative to making no adjustments at all (default Option 1). However, there may



be circumstances when option 2 might be considered. It is the most conservative option since stream flows are reduced rather than increased or left unaltered. If Option 2 is used in combination with the channel loss option, the loss factors  $CL(cp)$  are reflected in the computation of downstream negative incremental flow adjustments. The channel loss option is treated as an integral part of Option 2, and these two modeling features may be used in combination.

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

**Option 4** involves the same flow adjustments as option 3. However, in considering each water right in turn, the flow adjustment is made available at downstream control points but not at the control point of the right. For example, referring to column 7 of Table 3.4, the available flow of 81 ac-ft at CP-2 is determined as the minimum of the following values.

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

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

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

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

The channel loss option may be used in combination with negative incremental adjustment Option 4. However, the negative incremental flow adjustment is a correction for channel losses as well as other factors. Therefore, in the water rights computational loop, in determining water availability for a particular right in a particular month, the channel losses factors  $CL(cp)$  and

negative incremental flow adjustments are not both applied concurrently. Rather, each is applied individually, and the method providing the greatest water availability is adopted. As previously discussed, the model checks available stream flow at all downstream control points as well as at the control point at which the right is located. At each downstream control point, water availability is determined alternatively (1) using the  $CL(cp)$  to cascade back upstream and (2) applying the incremental flow adjustment. The method yielding the highest water availability is selected. Channel losses are identically the same with ADJINC of either  $-4$  or  $4$ . Channel losses are computed for all control points with non-zero  $CL(cp)$  either way.

In Example 3 presented in Figure 3.2 and Tables 3.3 and 3.4, if  $CL(cp)$  for control points CP-1 and CP-4 are 0.1 and 0.2, respectively, the available flow of 90 ac-ft at CP-2 is determined as the minimum of the following values.

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

$$\text{CP-2: } 90 = \text{maximum of: } \begin{array}{l} 81 / [1.0(1.0 - CL(I))] = 81 / 0.9 = 90 \\ 81 + 9 = 90 \end{array}$$

$$\text{CP-4: } 111 = \text{maximum of: } \begin{array}{l} 100 / [1.0(1.0 - CL(I))] = 100 / 0.9 = 111 \\ 100 + 4 = 104 \end{array}$$

$$\text{CP-6: } 112 = \text{maximum of: } \begin{array}{l} 80 / [(1.0 - CL(4))(1.0)(1.0 - CL(I))] = 80 / [(0.8)(0.9)] = 111 \\ 80 + 32 = 112 \end{array}$$

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

$$\text{CP-2: } 81$$

$$\text{CP-4: } 111 = \text{maximum of: } \begin{array}{l} 100 / [1.0(1.0 - CL(I))] = 100 / 0.9 = 111 \\ 100 + 4 = 104 \end{array}$$

$$\text{CP-6: } 112 = \text{maximum of: } \begin{array}{l} 80 / [(1.0 - CL(4))(1.0)(1.0 - CL(I))] = 80 / [(0.8)(0.9)] = 111 \\ 80 + 32 = 112 \end{array}$$

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

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

$$\text{CP-6: } 112 = \text{maximum of: } \begin{array}{l} 80 / (1.0 - 0.2) = 100 \\ 80 + 32 = 112 \end{array}$$

**Option 5** consists of computations within the water rights simulation. Regardless of negative incremental flow option, in *WRAP-SIM*, as each water right is considered in turn, the simulation proceeds through three steps:

1. The amount of water available to that right is determined based on stream flows at its control point and all downstream control points.
2. Water accounting computations are performed to determine stream flow depletion, reservoir evaporation, storage, diversion, shortage, and the other relevant quantities.
3. Stream flows at downstream control points are adjusted for the effects of the water right.

Option 5 is a modified version of the algorithms for steps 1 and 3 above. Incremental flows are not actually computed, and there is no negative flow adjustment array developed prior to the simulation like the other options.

Option 5 as well as Option 1 are based on the premise that upstream flow must be committed to satisfying downstream negative incremental flows along with senior downstream water right requirements. However, unlike Option 1, with Option 5 this premise is not adopted if: (1) there is no downstream senior water right that affects upstream water availability or (2) there is a discontinuity of flow between the CP of the downstream senior right and the upstream CP for which water availability is being determined. With no senior rights located downstream, water availability is not affected by negative incrementals at downstream control points. However, with senior rights located downstream and no flow discontinuity, Option 5 is equivalent to Option 1.

#### Comparison of Options 1, 4, and 5

Option 1 is the most conservative, and Option 3 the least conservative, from the perspective of limiting the amount of water available at an upstream location. Option 4 falls between Options 1 and 3. Option 5 falls in between Options 1 and 4 in the sense of being equivalent to Option 1 except where circumstances dictate switching to being essentially equivalent to Option 4.

The term *excess negative incremental flow* is adopted here to refer to the portion of a negative incremental flow not accounted for by the channel loss factor.

- Option 1 is based on the premise that flow at upstream locations must be committed to mitigating excess negative incremental flows at downstream control points prior to meeting downstream water right requirements.
- Option 5 is likewise based on the premise that upstream flow must be used to supply excess negative incremental flow prior to meeting downstream water right requirements, unless: (1) there is no downstream senior water right that affects upstream water availability or (2) there is a discontinuity of flow between the control point of the downstream senior right and the upstream control point for which water availability is being determined.
- Option 4 is based on the premise that negative incremental flows at downstream control points do not affect water availability at an upstream control point. Flows have to be passed to meet water right requirements at downstream control points, adjusted by CL channel loss factors. However, water availability at an upstream control point is not reduced for negative incremental flows assigned to other control points located downstream of it.

The other key difference between the options relates to flow adjustments for the effects of a stream flow depletion. In cascading flow reductions downstream, Options 1 and 4 will allow the flow at a downstream CP to be reduced more than the total regulated flow of another intermediate CP located upstream. Conversely, Option 5 limits the flow adjustment to not exceed the regulated flow at the intermediate CP.

The following Examples A-D are used for illustration. Referring to Example A, with either Option 1, 4, or 5:

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

Options 1 and 5 are based on the premise that the monthly flow of 40 at CP3 in Example A came totally from the same-month flow of 100 at CP1 and 110 at CP2. None of the 40 was derived from the incremental watershed between CP1 and CP3 or from previous-month flow at CP3. With Option 1, water availability at CP1 is limited by the flow at CP3 regardless of whether there is a senior right at CP3. With Option 5, water availability at CP1 is limited by the flow at CP3 only if there is a senior right at CP3. With Option 4, water availability at CP1 is not limited by negative incremental flow occurring downstream.

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

CP1: 100  
↓  
CP2: 110  
↓  
CP3: 40

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

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

computed as follows

Option 1	Option 4	Option 5
$40/0.5=80$	$\text{Min}[100 \text{ and maximum of } (40+70=110 \text{ and } 40/0.5=80)] = 100$	100 at CP1
$10/0.5=20$	$\text{Min}[100 \text{ and maximum of } (10+70=80 \text{ and } 10/0.5=20)] = 80$	$10/0.5=20$

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

CP1: 100  
↓  
CP2: 110  
↓  
CP3: 0

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

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

computed as follows

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

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

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

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

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

computed as follows

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

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

Amount of Water Available to a Right WR1 at Upstream CP1

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

computed as follows

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

**Selection of a Negative Incremental Flow Option**

Selection of the optimal negative incremental flow option for a particular river basin is based on judgment considering the factors most likely to be contributing most to causing the negative incremental flows. Selection of methods for dealing with negative incremental flows is complicated by the fact that the combination of factors causing the negative incrementals may vary between months and between control points. The basic reasons for negative incrementals are as follows.

1. permanent channel losses over and above those modeled by the channel loss coefficients
2. channel losses, again over and above those captured by the channel loss coefficients, where bank storage or underflow may reenter the stream at a downstream location and/or during a future time period

3. timing effects of the runoff from a rainfall event reaching an upstream control point in a particular month but reaching a downstream control point early the next month
4. errors and lack of precision in stream flow measurements at the gages and in computations to convert gaged flows to naturalized flows

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

With options 1 and 5, the amount of water available to a right is reduced by negative incremental flows occurring at downstream control points. With options 3 and 4, water availability is not affected by negative incremental flows assigned to control points located downstream. A key hydrologic question is as follows. In order for sufficient water to be physically available for senior water right requirements at downstream locations, must upstream water rights allow sufficient stream flows to pass their locations to cover the negative incremental flows (assumed to be channel losses) occurring in river reaches in between.

A policy question to be considered in comparing options is as follows. Is a water right required to allow stream flows to pass its location in order to mitigate negative incremental flows (assumed to be channel losses) occurring in river reaches located downstream. In all cases, stream flows are allowed to "*pass through*" to accommodate senior water rights located downstream. However, does the amount of flow committed to the downstream rights include channel losses as well as diversion, instream flow, hydropower, and storage requirements? In the extreme case, curtailment of an upstream junior right may, due to channel losses, result in little or no increase in water available to the downstream senior right. Senior rights are protected in *SIM* regardless of negative incremental flow option. The options differ in regard to how protection of a senior downstream right affects water available to upstream more junior rights.

Default negative incremental flow Option 1 includes no provisions designed specifically to address the issue of negative incremental flows. Options 2, 3, and 4 are based on computing incremental flows at the beginning of the simulation. Options 2 and 3 adjust the naturalized flows to remove the negative incrementals at the beginning of the simulation and thus do not require modifications to the routines in the water rights priority loop. Option 4 computes an adjustment array at the beginning that is used during the simulation in several routines in the model. Option 5 is a modified version of the water right simulation algorithms. With Option 5, incremental flows are not actually computed, and there is no negative flow adjustment array.

The types of circumstances for which each option is most applicable is subject to investigation and debate. However, the following general observations are reasonably valid.

- Option 1 is the most conservative in limiting available flows. It provides the conservatively low extreme of water availability estimates. Option 1 is useful if the model-user chooses to be conservative (under-estimate the amount of water available to rights) with respect to the effects of negative incremental flows. It is also useful in sensitivity study runs testing the effects of the other options on simulation results.

- Option 2 is similar to the approach mentioned below involving adjustments with spreadsheet computations to remove the negative incremental flows prior to applying *WRAP*. Option 2 is useful for sensitivity studies but would seldom, if ever, be adopted for a final simulation.
- Option 3 is the opposite extreme to Option 1. Option 3 provides high estimates of water availability. Negative incremental flows have no effect in regard to reducing water availability. Option 3 is useful for sensitivity studies but would seldom, if ever, be adopted for a final simulation.
- Option 4 is generally the optimal choice for most situations.
- Option 5 relates best to situations characterized by both of the following conditions:
  1. The dominant cause of negative incremental flows is permanent channel losses not modeled by the channel loss factors.
  2. The water rights system requires that upstream junior water users curtail their use to allow pass-by flows to mitigate downstream channel losses in addition to meeting downstream senior water right diversion, instream flow, and storage amounts.

Option 1 is also applicable in these situations, but Option 5 is less overly conservative than option 1.

Another approach for dealing with negative incremental naturalized flows is to adjust flows with spreadsheet computations to remove the negative incrementals prior to applying *WRAP*. Flows subtracted in one month may be added back in the next month. *WRAP* Option 2 similarly reduces flows to remove negative incrementals but does not add the reductions to the next month flows. Options 4 and 5 are probably almost always better than making adjustments outside of *WRAP-SIM*. Options 3 and 4 routines for computing incremental flows are too complicated to perform conveniently with a spreadsheet program. Options 4 and 5 computations are an integral part of the simulation and can not be performed external to *WRAP-SIM*.





## CHAPTER 4 WATER MANAGEMENT FEATURES

A *WRAP-SIM* simulation combines

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

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

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

### Water Rights

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

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

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

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

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

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

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

## Water Right Priorities

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

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

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

1. A priority number for each water right is entered in field 5 of its *WR* or *IF* records. A blank field 5 is read as a priority number of zero. If two or more rights have the same priority number, they are ranked in the same order as their *WR* or *IF* records are entered in the input file.
2. Factors entered on a use priority *UP* record replace or modify the *WR/IF* field 5 priority numbers for all *WR* and *IF* records having the same water use type identifier as the *UP* record.
3. *JO* record field 9 activates optional methods for assigning priorities that replace the priorities assigned in *WR* and *IF* record field 5. These options set priorities either automatically in upstream-to-downstream order (*JO* record field 9 option 1) or based on the order in which *WR/IF* records (option 2) or *CP* records (option 3) are placed in the *DAT* input file.
4. Options provided on *PX/AV* and *EA/EF/AF* records allow two or more rights to share the same priority. Stream flow and storage are allocated between these rights in accordance with rules governed by parameters provided as input by the model-user.

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

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

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

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

The following options replace the priorities entered in *WR* and *IF* record field 5. The *WR/IF* field 5 priority number is ignored. The switch parameter *NPOPT* in *JO* record field 9 activates three alternative options for setting priorities.

*JO* record field 9 option 1 provides the capability to conveniently simulate water management in a river basin that has no water allocation priority system. Without a water rights permit system or some other regulatory mechanism to allocate water, water availability for each water user is affected by other water users located upstream but not by those downstream. Priorities may be manually assigned to each water right to simulate this upstream-to-downstream natural priority system. However, *JO* record option 1 allows the upstream-to-downstream priorities to be activated automatically. *SIM* internally assigns priority numbers to water rights based on the location of their control points. The control points are automatically assigned integer priority numbers starting with 100 and increasing in increments of 100 following the criterion that the integer assigned to any control point is smaller than the number assigned to any other control point located downstream. For control points on parallel tributaries, those listed in the input file first are considered first in the algorithm and get the smaller priority number. Each water right is then assigned the number associated with its control point. For multiple rights at the same control point, the priority number is incremented based relative priorities on their *WR* and/or *IF* records. For example, four water rights at a control point with priority number 800 will be assigned priority numbers 800, 801, 802, 803 based upon the relative priorities on their *WR* or *IF* records.

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

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

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

## **Water Availability within the Priority-Based Water Rights Computation Loop**

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

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

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

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

## Specifying Targets and Rules for Meeting the Targets

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

Table 4.1 provides a categorization of the different types and features of water rights. The input records used to activate the various features are also shown. In *WRAP* terminology, a water right is a water management scheme described by the information entered on either a *WR* record or *IF* record along with auxiliary records tied to the *WR* or *IF* record. *WR* records specify requirements for water supply diversions and return flows or hydroelectric energy generation. *WR* records are also used to refill/maintain storage in reservoirs at specified capacities subject to water availability. *IF* records are used to establish instream flow targets, typically associated with environmental needs, and optionally may include releases from storage to meet flow targets.

A *WR* record right, with associated *WS* record, may include refilling storage in one reservoir called its *primary* reservoir. An instream flow, water supply diversion, or hydroelectric energy generation requirement may be met by stream flow and/or releases/withdrawals from the primary reservoir and multiple secondary reservoirs. *Secondary* means the reservoir releases to meet instream flow, diversion or hydropower targets associated with the water right, but its storage is not refilled in association with that particular right. It is refilled by one or more other rights (sets of *WR/WS* records). Multiple rights with different priorities may refill storage to different levels in the same reservoir. Run-of-river diversion or hydroelectric energy generation rights may be modeled by specifying zero active storage capacity. *WR/WS* records may also specify a storage-only right with zero entered for the diversion target.

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

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

Table 4.1  
Classification of Water Right Features

---

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

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

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

- constant annual amount combined with monthly distribution factors (*WR/IF* fields 3-4, *UC*)
- target series that vary between years as well as between months of the year (*TS* record)
- specification of diversion and instream flow targets as a function of naturalized/regulated/unappropriated flows, reservoir storage, and/or stream flow depletions (*TO*, *FS* records)
- drought index that allows diversion, instream flow, and hydropower requirements to vary as a function of reservoir storage (*DI*, *IS*, *IP* records; *IF* record field 8; *WR* record field 10)

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

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

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

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

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

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

*Type 4:* flow is discharged into the stream

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

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

*Type 7:* reservoir storage refilling target is determined and applied

---



In addition to the features listed in Table 4.1, a watershed flow option for distributing naturalized flows may be activated by the *SO* record. The watershed flow option is described in Chapter 3 along with the other flow distribution methods. It is different than the other methods in regard to being associated with a water right (*WR* record) rather than a control point (*CP* record).

Water management and use requirements are based on meeting:

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

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

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

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

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

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

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

The next section outlines the system for setting water management/use targets (Task 1). Features for modeling operating rules for meeting the targets (Tasks 2 & 3) are then described. The chapter then covers the details of reservoir system storage and operations, water supply diversions and return flows, hydroelectric energy generation, environmental instream flow requirements, and modeling water management schemes that circumvent the priority sequence.

### **Setting Diversion, Instream Flow, and Hydropower Targets**

In many typical modeling applications, targets are defined by simply entering an annual target amount on a *WR* or *IF* record and a set of 12 monthly distribution factors on *UC* records. The targets vary seasonally but are constant from year to year. However, targets may also be entered for each individual month of the multiple-year period-of-analysis, varying from year to year as well as seasonally. Options also provide flexibility for defining targets as a function of reservoir storage, current or accumulated past river flows and/or stream flow depletions appropriated by specified rights, as well as month of the year.

Water use requirements may be specified by a single option in *SIM*, or alternatively, requirements may be computed within the model by combining multiple optional features. For

most typical water rights, targets are defined by simply entering an annual target amount on a *WR* or *IF* record and monthly distribution factors on *UC* records. However, ingenuity may be applied to combine several options to model complex water management situations.

In a given month of the simulation, as the water rights are considered in turn in priority order, *SIM* builds monthly diversion, instream flow, or hydroelectric energy targets in sequential steps as outlined below. Embedded within the other sequentially ordered steps governed by *WR/IF/UC*, *BU*, *DI/IS/IP*, *TO*, *TS*, *FS*, and *SO* records, step 4 below may also be a series of target building steps with each step being governed by a separate *TO* record.

1. The model combines the annual diversion, hydroelectric energy, or instream flow requirement amount entered in a *WR* or *IF* record with monthly distribution coefficients from *UC* records to obtain a target for each of the 12 months of the year. *UC* records are not required if the monthly target is constant over the year.
2. The backup option activated by the *BU* record allows a water right to serve as a supplemental backup right for one or more other rights. Shortages incurred by the other rights are added to the target of the backup right. The shortage may be added at this step or as step 9.
3. The optional drought index defined by a set of *DI/IS/IP* records modifies the target as a function of the storage content of specified reservoirs. The drought index may be applied here as step 3 or later as step 6. The location of the drought index adjustment in the computational sequence is specified with the *DINDEX* entry on the *IF* or *WR* record.
4. *SIM* uses several variables entered on one or multiple *TO* records to build diversion and instream flow targets. Targets may be a function of naturalized, regulated, or unappropriated flow multiplied by a factor. The target may be set based on reservoir storage or stream flow depletions incurred by other rights, which may also be multiplied by a factor. Upper and lower bounds on the target may be applied in two different ways here in the repetitive step 4.

Several *TO* records may be used to build a target step-by-step. The first *TO* record results in a target to be combined with the target determined in the preceding steps outlined above. Each subsequent *TO* record results in another target to be combined with the preceding cumulative target. The two intermediate targets are combined in each step by either (a) selecting either the maximum or minimum or (b) adding them. The target developed in this manner may be a function of the summation of naturalized, regulated, and/or unappropriated stream flow at multiple control point locations, stream flows at various locations, reservoir storage, stream flow depletions by other water rights, and/or user specified lower and upper bounds. Flexibility is provided for combining these features as needed.

5. A time series of monthly diversion, hydroelectric energy, or instream flow targets for each month of the hydrologic period-of-analysis may be entered on *TS* records. The *TS* record may be the only option used for a particular water right, or *TS* record targets may be combined with the other options. Either (a) the greater or lesser or (b) the summation or product of the steps 1–4 versus step 5 values for a particular month is adopted depending on the value for *TSL* entered in the second field of the *TS* record for the first year.

6. A drought index defined by a set of *DI/IS/IP* records modifies the target determined above as a function of the storage content of specified reservoirs. The drought index may be applied at this step in the sequence or as step 3 above.
7. The target may be constrained by upper and lower limits entered on a *TO* record.
8. A flow switch *FS* record may modify the target based on accumulated regulated, naturalized, or unappropriated flow, diversions or stream flow depletions, or control point inflows. One of two alternative multipliers are applied to the target depending on whether the defined flow variable at a specified control point during the current month or accumulated during the past period of any number of months fall within a specified range.
9. The backup option activated by the *BU* record may be applied as either steps 2 or 9. 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.

The options outlined above are applied in sequential order within *SIM* to set targets. Other parameters on a *SO* record may limit the amount of water available to a water right. Water availability for a right may be limited by monthly or cumulative seasonal or annual limits on stream flow depletions and the amount of water that may be withdraw from reservoir storage. An annual or seasonal diversion limit may also be placed on the total water diverted by a right.

#### *Diversion and Instream Flow Targets as a Function of Stream Flow, Storage, and Other Rights*

The target options *TO* record provides options described as Step 4 on the preceding page for computing monthly diversion or instream flow targets as functions of (a) naturalized, regulated, or unappropriated stream flow, (b) reservoir storage or storage drawdown, (c) water taken from stream flow or reservoir storage by other rights, and (d) user-specified upper and lower bounds. Storage drawdown is capacity less storage content. The targets may be functions of stream flows or storage optionally in either the previous month or current month. If the current month option is adopted, unappropriated stream flow is the flow that is still unappropriated at the step in the water rights priority loop computations at which the right is considered. Likewise, with the current month option, the regulated flow and end-of-period storage reflect only the effects of senior rights.

Considerable flexibility is provided to creatively combine target-building features in a variety of ways to model a broad range of possible water management situations. Targets could be computed by the model by adding and/or subtracting stream flows at any number of locations; combining other types of flows at other locations; adopting the minimum or maximum of these values; and placing upper and lower bounds on the flows. Stream flow falling within different bounds may be multiplied by different factors. A reservoir may be refilled with a diversion with the target determined based on the reservoir drawdown limited by regulated flows. Targets may depend upon the amount of water taken by other water rights. The *TO* record options may also be combined with drought index *DI/IP/IS*, flow switch *FS*, and target series *TS* records. Innovative strategies for combining options may be adopted to model complex and unique water management situations.

The following simple example illustrates the general approach of applying *TO* records. Examples in Appendix B provide further illustration.

*Example:* Subject to water availability, regulated flows at control point CP1 are maintained to not fall below the minimum level defined by the following instream flow target. The target is set as a function of naturalized flows at CP1 and the summation of available flows at CP2 and CP3. Available flows are the unappropriated stream flows considering all water rights that are senior to this right. For each month, the target is set at 25 percent of the total sum of the unappropriated flows at CP2 and CP3, except the target can not exceed the naturalized flow at CP1. Another feature of the instream flow requirement is that the target must fall within the range of 100 to 500 acre-feet/month, regardless of the flows at CP1, CP2, and CP3. This target is specified by the following *IF* and *TO* records.

```

**
**
** | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10
**
IF CP1 1985
TO 3 0.25 CP2 CONT
TO 3 .25 ADD CP3 CONT
TO 1 CP1 MIN 100. 500.
**

```

Although each *TO* record results in a cumulative intermediate target, only the final target is used in the simulation computations. For purposes of illustration, assume that in a particular month of the simulation, the naturalized flow at CP1 is 635 ac-ft and *WRAP-SIM* computes available flows of 800 and 400 ac-ft at CP2 and CP3. The target is set by *WRAP-SIM* step-by-step as follows.

```

IF CP1 1985
TO 3 0.25 CP2 CONT

```

The first intermediate target is computed as:  $(0.25)(800) = 200$  ac-ft

```

TO 3 .25 ADD CP3 CONT

```

The target is computed as:  $200 + (0.25)(400) = 300$  ac-ft

```

TO 1 CP1 MIN 100. 500.

```

The target is the minimum of 300 or  $(1.0)(635)=635$  which is 300 ac-ft.

The target is the maximum of 300 or the lower limit 100 which is 300 ac-ft

The target is the minimum of 300 or upper limit of 500 which is 300 ac-ft.

Thus, in the example, *SIM* determines a minimum instream flow target of 300 ac-ft for that month. This target was built step-by-step by combining several options.

### Diversion, Hydropower, and Instream Flow Targets Series Entered on TS Records

The purpose of the target series *TS* record option is to provide flexibility for diversion, instream flow, or hydropower targets to be developed outside of the model and entered as input. The targets entered on *TS* records may be determined by various means independently of *SIM* or perhaps from previous simulations performed with the model. The *TS* record targets may be the only requirements specified for a particular water right or alternatively may be integrated with the other options. Targets from *TS* records are integrated into the sequential step-by-step *SIM* target building scheme as Step 5 as previously outlined. *TS* records may be used to modify targets computed within the model with other options. Targets may be arithmetically manipulated by adding, subtracting, or multiplying numbers from *TS* records.

The target series *TS* records allow monthly diversion, instream flow, and hydropower demands to be specified that vary between years as well as seasonally. If the *TS* option is adopted, targets cover every month of the hydrologic period-of-analysis. However, the number of *TS* records may range from one to the total number of years in the simulation. The 12 monthly targets entered on a *TS* record may represent just one year or be repeated for any group of years or the entire simulation period.

### Drought or Storage Index

The various options activated by the *WR*, *IF*, *SO*, *TO*, *FS*, *TS*, and *DI/IP/IS* records may be combined in a myriad of ways to define diversion, instream flow, and hydropower targets. The drought or storage index option defined by *DI*, *IP*, and *IS* records may be combined with the other records in the target building process or alternatively may be applied independently.

The term *drought index* is adopted because depleted storage is viewed as an indicator of prolonged dry conditions with diminished water resources. The drought index option allows instream flow, diversion, and hydropower requirements to vary with reservoir storage content. The drought index option may be used as a mechanism for modeling reservoir system operations. However, more generically, a drought index can be used to allow any water use target to vary as a function of storage content, including instream flow, run-of-river diversion, and other water use requirements not met by releases from the reservoirs included in the drought index. This feature may be adopted for any application in which water use requirements are expressed as a function of reservoir storage. *JO* record field 8 is a switch allowing either beginning-of-month storage or the latest end-of-month storage computed in the water right priority loop to be used for the index.

Drought indices are assigned integer identifiers (1, 2, 3, ...) in the sequential order that the *DI/IS/IP* records for each index are entered in the input file. Entering one of these integer identifiers in field 8 of an *IF* record or field 10 of a *WR* record connects a water right to a drought index. Any number of water rights can be assigned the same drought index, and there can be any number of drought indices.

Each drought index consists of a drought index reservoirs *DI* record and drought index storage *IS* versus percentage *IP* records. The *DI* record specifies the selection of reservoirs upon which to base the index. Either all of the reservoirs in the model or a selection of up to 12 reservoirs

may be specified. The *IS* and *IP* records provide a table of reservoir storage versus percentage. The reservoir storage values on the *IS* record refer to the total storage content of the reservoirs specified by the *DI* record. The corresponding percentage on the *IP* record are factors by which the instream flow, diversion, and/or hydroelectric energy requirements are multiplied.

The inclusion of certain reservoirs in the drought index assigned to particular water rights does not otherwise associate the reservoirs with the water rights. *WS* and *OR* records are connected to *WR* and *IF* records identically the same with or without assigning a drought index to the *WR* record. Instream flow, diversion, and hydropower generation requirements associated with a water right may be determined as a function of a particular drought index without the *DI* record reservoirs making releases for these requirements or being otherwise associated with the right.

Drought indices are incorporated in the *SIM* simulation computations as follows.

1. A parameter entered in *JO* record field 8 allows either beginning-of-month storage or the latest end-of-month storage computed in the water right priority loop to be used for the index. Either at the beginning of the month or at the pertinent point in the priority sequence, the storage contents of the specified reservoirs are summed to obtain a total storage for the drought index. All of the reservoirs in the model or up to 12 reservoirs can be selected for each drought index.
2. Linear interpolation is applied in combining the total storage associated with a particular drought index with the storage versus percentage relationship from the *IS/IP* records to obtain a multiplier factor expressed as a percentage.
3. The percentage converted to a fraction is multiplied by the permitted instream flow, diversion, and/or hydroelectric energy targets for each right assigned to a particular drought index.
4. After adjusting the target instream flow, diversion, and hydropower amounts in the previous step, all computations proceed normally without any other change related to the drought index.

A drought index is normally used to express a diversion, instream flow, or hydropower target as a function of the storage content of one or more actual reservoirs. However, other innovative types of applications are also possible. For example, a drought index may be used to specify targets as a function of cumulative flows or diversions. A diversion may be a function of the cumulative total amount previously diverted that year by certain water rights. Freshwater inflows into a bay and estuarine system may be expressed as a function of cumulative inflows to date that year. A *computational* reservoir with zero evaporation may be placed at the basin outlet to model the accumulation of inflows into a bay or estuary. The zero-evaporation, zero-inflow *computational* reservoir could be assigned a control point not connected to the system to model a sink or accumulation of diversions that are transported to the *computational* reservoir as return flows. The switching-variable *EMPTY* of the *DI* record is designed to facilitate this type of application. The reservoir may be emptied either every month or annually on a specified month of the year. In the model, the water from the reservoir is loss from the system.

#### Flow Switch for Adjusting Targets Based on Accumulated Flow Volumes

The flow switch *FS* record activates a feature allowing instream flow, diversion, and hydropower targets to be switched on/off or otherwise adjusted depending on whether the

accumulated volume of a selected flow variable in the current and/or any number of preceding months falls within a specified range. The primary motivation for this feature is flexibility in modeling instream flow requirements that are expressed as a function of whether current and/or accumulated past flows at a specified location fall within a specified range. However, the *FS* record options may be also applied in setting water supply diversion, hydropower generation, and reservoir storage targets.

*SIM* keeps track of the total volume of the defined flow variable at a specified control point that has accumulated over the preceding user-defined number of months. Any number of months may be specified. The *FS* record target setting rules are based on specifying two different factors which may be zero, 1.0, or any other number. The target is multiplied by one of the two alternative factors each month. The choice of factor depends on whether or not the cumulated flow falls within a user-specified range.

### **River/Reservoir System Operating Rules for Meeting Water Use Requirements**

Modeling river/reservoir/use system operations may range from very simple to quite complex. Flexible options are provided to model the rules by which stream flow and reservoir storage is allocated to meet the water use targets described in the preceding section. Table 4.1 outlines the optional water rights features for modeling various complexities or different situations. The preceding section focuses on options for setting targets modeling water supply diversion, environmental instream flow, and hydroelectric energy production targets (demands, needs, requirements). The following discussion describes options to be adopted in various combinations to model the manner in which the river/reservoir system is managed to meet these water use targets.

#### **Secondary Backup Right**

The secondary backup option allows diversion, instream flow, or hydropower shortages associated with a water right to be supplied by another right called a backup right. The backup option is activated by a *BU* record assigned to the right providing the backup. The *WR* or *IF* record right with a *BU* record serves as a backup for any number of other rights. The diversion, instream flow, or hydropower shortages computed for the one or more specified other water rights are added to the target of the backup right. The computations then proceed normally without any other change related to the backup feature. In each month, the target for the backup right is the shortage of the rights being backed up plus the target amount determined by its own *WR/IF/UC* records and target setting options on associated *SO/TO/TS/DI/FS* records. A backup right may also be combined with the *PX* record control point limit option discussed in the last section of this chapter.

Shortages incurred by the specified rights are added to the target of the *BU* record right within in the water rights priority loop computational sequence. If the other right is senior to the backup right, its shortage is added to the target of the backup right in the same month. If the other right is junior, its shortage is added to the backup right target in the next month.

A backup right may backup another backup right. Any number of backup rights may be placed in sequence. Each adds any shortage amount computed for the preceding backup right to its own target. Thus, a single diversion requirement can be shared by multiple rights.

Though rendered obsolete with introduction of the expanded features provided by the newer *BU* and *PX* records, *SO* record field 6 is still functional. The *SO* record field 6 option with *RETURN* entered may be used in combination with a type 4 right to assign a priority to a return flow that is different than the corresponding diversion right. A *WR* record for a type 4 right along with its *SO* record may be placed behind the *WR* and supporting records for a more senior diversion right. The diversion shortage for the first right will be applied in computing the amount *AMTRF* that the second right (type 4 right) returns to the stream as follows:

$$AMTRF_{type\ 4\ right} = T_{type\ 4\ right} - (S_{previous\ right}) (RFA_{type\ 4\ right})$$

where the target amount *T* for the type 4 right is computed as normal and then adjusted for the shortage *S* from the previous right. The more recently added transient water right *XP* option 1 activated by the *PX* record provides a simpler means to assign a different priority to return flows.

### Stream Flow Depletions from Multiple Locations

Stream flow depletions to meet diversion requirements and refill reservoir storage normally occur at the control point to which the water right is assigned. This control point is specified in the second field of the *WR* record. Diversion and reservoir refilling requirements can also be met by releases from storage from one or multiple secondary reservoirs identified on *WS* records with system operating rules specified on *OR* records.

An option allows reservoir storage to be refilled from stream flow depletions at other control points. The input variable *ACPID* (alternate control point identifier) entered in the *SO* record specifies the location from which flow depletions are made. Any number of *WR/SO* records, and thus alternate control point locations, can be associated with a particular reservoir. There are no restrictions on which control points to use to refill storage. The computations are based on using the alternate control point in lieu of the default control point specified in the second field of the *WR* record.

A typical application of this feature would be a storage reservoir located on a small tributary that is filled by pumping water from a nearby major river as well as the inflows from its own watershed. A *WR/WS/SO* record set allows the reservoir to be refilled from inflows from the small stream on which it is located. In months in which these inflows are insufficient to fill the reservoir to capacity, a second *WR/WS/SO* record set with an alternate control point allows the reservoir to pump water from the other stream.

### Limits on Stream Flow Depletions, Diversions, and Diversions from Storage

*SO* record variables *MRW* and *ARW* are limits on monthly and seasonal or annual withdrawals from reservoir storage. An annual or seasonal diversion limit *ADL* may also be entered on the *SO* record. For annual limits, starting in the first month of each year, the model maintains a record of the total cumulative stream flow depletions, diversions, and the amount of the diversions that came from reservoir storage that year associated with the specified water right. Upon reaching a specified limit, no more water is available to the diversion right until the beginning of the next year. Likewise, the limit months *LM(wr,1)* and *LM(wr,2)* entered on the *SO* record define beginning and ending months of a season for which the limits apply.



Water right permits associated with off-channel reservoirs often limit the total cumulative amount of stream flow that may be taken each year to refill reservoir storage. Pumping and conveyance facilities as well as water rights permits may limit the amount of stream flow withdrawn each month. Options allow monthly and annual limits to be imposed on stream flow depletions associated with a water right. Without specifying this option, reservoir storage is refilled to capacity each month as long as sufficient stream flow is available to a right. The options for specifying flow depletion limits are motivated primarily by constraints on refilling off-channel reservoir storage but are applicable to major main-stream reservoirs and diversions as well. *SIM* does not explicitly differentiate between on-channel and off-channel reservoirs, and these options may be applied to either.

A stream flow depletion is the amount of water taken from stream flow by a right to meet diversion requirements, net evaporation-precipitation requirements, and refill reservoir storage. The input variable *ANNDEP* of the *SO* record is a limit on the cumulative annual flow depletion that a right is allowed. Starting in the first month each year, the model maintains a record of the total stream flow depletions that a right has accumulated that year. Reservoir storage refilling and diversion associated with the right (*WR/WS* records) is curtailed whenever the *ANNDEP* limit is reached. The limit is treated as another constraint on water availability.

Monthly limits on the stream flow depletions associated with a water right can also be imposed. The input variable *MONDEP* of the *SO* record is a constant limit imposed each of the 12 months of the year. The amount of stream flow available to a right is constrained to not exceed *MONDEP* in any month. Alternatively, a set of 12 monthly varying limits may be specified for a right on a *ML* record.

Specifying River/Reservoir System Operating Rules Based on Water Right Types 1 to 7

As indicated by Tables 4.1 and 4.2, all *WR* record water rights are categorized as being either type 1, 2, 3, 4, 5, 6, or 7 by the entry in field 6 of the *WR* record. This scheme of water right types is used to specify certain basic rules for meeting diversion or hydroelectric energy requirements from stream flow and reservoir storage and for refilling reservoir storage. The kinds of river/reservoir system operations associated with each type of water right are summarized in Table 4.2 and described in the following paragraphs.

Table 4.2  
Water Right Types 1, 2, 3, 4, 5, 6, and 7

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

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

If one or more *WS* records are connected to an *IF* record, reservoir operation is equivalent to *WR* record type 2. Releases are made from the reservoirs to meet the instream flow requirement. However, an *IF* record does not refill storage. In general, all junior rights must pass inflows through their reservoirs to meet downstream instream flow requirements. Using one or more *WS* records to assign reservoir storage to an *IF* record right is relevant only if releases from storage are required, in addition to passing reservoir inflows, to meet instream flow requirements.

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

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

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

*Type 4 right.*- With a type 4 right, the annual amount *AMT* entered in *WR* record field 3 is discharged into the stream. The stream inflow amounts resulting from type 4 rights are found in the simulation results as return flows. A type 4 right may model an interbasin transfer of water through conveyance facilities, return flow from groundwater sources, or other situations involving discharge of water into the river system within the water rights priority computation loop sequence. The target amount is computed for a type 4 right just like any other type of right. The difference is that a type 4 right is not a diversion from the stream, but rather an inflow to the stream. After the monthly amount is determined just like a diversion target, it is then multiplied

by the return flow factor *RFAC* from *WR* field 8 and treated computationally as a return flow. *RFAC* is assigned a default of 1.0 if the *RFAC* field is blank. All return flow options are valid, except monthly return factors (*RF* records) can not be used. Water availability computations are not relevant and are not performed for a type 4 right. The flow is entered into the stream system; it is not taken from stream flow, reservoir storage, or any other source included in the model.

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

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

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

#### *Primary and Secondary Reservoirs*

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

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

The water right type specified on the *WR* record guides the computations within the *WRAP-SIM* water rights loop. The type specification primarily affects the determination of the target requirement for the right and the manner in which the requirement is to be met. The available

stream flow is calculated the same regardless of water right type, except hydropower rights are not subject to instream flow requirements. The target stream flow depletion is then computed according to the type of right.

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

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

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

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

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

### **Reservoir Storage**

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

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

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

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

### Storage Capacity Versus Surface Area and Elevation Relationships

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

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

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

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

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

### Monthly Varying Limits on Storage Capacity

The monthly varying storage capacity option is motivated primarily by seasonal reallocations of storage capacity between flood control and water supply in multiple-purpose reservoirs. Seasonal rule curve operating rules consist of varying the top-of-conservation pool or other designated pool levels with season of the year. Probably the most common use of seasonal rule curve operations is in allocating storage capacity in multiple-purpose reservoirs between flood control and conservation pools, based on seasonally varying characteristics of water supply

and flood risk. The flood control pool consists of storage capacity above the designated top of conservation pool elevation that is kept empty except during and following major flood events. The bottom of the flood control pool coincides with the top of the conservation pool. A seasonal rule curve consists of varying the specified top of conservation pool elevation over the year.

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

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

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

#### Reservoir Storage Content at the Beginning of the Simulation

By default, all reservoirs are assumed to be full to their maximum storage capacity at the beginning of the simulation. If not specified otherwise, reservoirs start the simulation full. A less than capacity beginning storage content for any reservoir may be specified on its *WS* record. Another set of beginning-ending storage (BES) options is described in Chapter 2 that allows the storage at the beginning and end of the simulation to be the same, representing an infinite recycling of the hydrologic period-of-analysis. Any other beginning storage can also be defined in a BES file.

#### Reservoir/River System Operations

With a little ingenuity and imaginative creativity, *SIM* water right options may be integrated in a variety of ways to model a comprehensive range of reservoir system operating scenarios. Considerable flexibility is provided to simulate complex system operations by combining:

- a storage *WS* record for each reservoir associated with a water right defining storage capacities and operating parameters

- previously discussed water right features associated with *WR* and *IF* records and auxiliary *SO*, *ML*, *TO*, *FS*, *BU*, and *TS* records including the river/reservoir system operating rules specified by categorizing a right as type 1, 2, 3, 4, 5, 6, or 7 (*WR* record field 6), target setting options, and various other types of options specified on the auxiliary records
- previously discussed drought indices allowing diversion, instream flow, hydropower, and storage targets to be specified as a function of reservoir storage content (*DI/IS/IP* records)
- previously discussed monthly varying limits on storage capacity (*MS* record)
- multiple reservoir system operating rules discussed next (*OR* record)
- multiple owners sharing storage in the same reservoir discussed later (*EA* record)
- hydroelectric power features of a project discussed later (*HP* record)
- priority sequence circumvention options discussed in the last section of this chapter (*PX* records)

Most aspects of modeling water rights covered in the preceding sections of this chapter are relevant to reservoir system operations. The following discussion focuses on (1) multiple rights associated with the same reservoir and (2) multiple reservoirs associated with a single right.

### **Multiple-Reservoir and Multiple-Right Reservoir Systems**

A *WRAP-SIM* water right may include:

1. maintaining (refilling) the storage in one reservoir
2. meeting diversion, hydropower, or instream flow requirements by diverting or releasing from storage in one or multiple reservoirs

In constructing a model, these two activities can be viewed as being essentially separate. A particular right may include either, neither, or both. Reservoir storage capacity is provided on the *WS* record associated with a water right. Any number of water rights can be associated with a single reservoir, with each right filling the reservoir to a different storage capacity and/or using the reservoir to meet its water use requirements. *SIM* allows releases from multiple reservoirs to meet the one diversion, hydropower, or instream flow target and maintain storage in the one reservoir specified by a single water right. As discussed later, the model includes options for specification of multiple-reservoir/river system operating rules (*OR* record). Multiple reservoirs can each have one or more separate rights to maintain their individual storages. Reservoir system operations may be defined by combining any number of *WR/WS* records and other supporting records.

Each reservoir is associated with at least one water right. Each reservoir is assigned a control point. Multiple rights and multiple reservoirs may be assigned to the same control point. Each water right has access, in priority order, to the stream flow inflows at the control point. Each right may have multiple reservoirs (one primary and the others secondary).

As discussed in the preceding section, each reservoir must have one and only one storage volume versus surface area relationship entered either as *SV/SA* records or as coefficients on a *WS* record. Each reservoir associated with hydroelectric power must have one and only one storage volume versus elevation relationship entered as *PV/PE* records. The *MS* record option allows each reservoir to have one (or none), but not more than one, set of 12 monthly storage capacity limits. However, each reservoir may be assigned to any number of water rights.

As illustrated by Figure 4.1, a reservoir includes an active pool and inactive pool. The inactive pool capacity specified in *WS* record field 7 is dead storage from which releases or withdrawals cannot be made by that right. In the computations associated with that right, the inactive pool can be drawn down only by evaporation. No evaporation occurs from the inactive pool unless the active pool is empty. Different water rights associated with the same reservoir can each have a different inactive pool capacity.

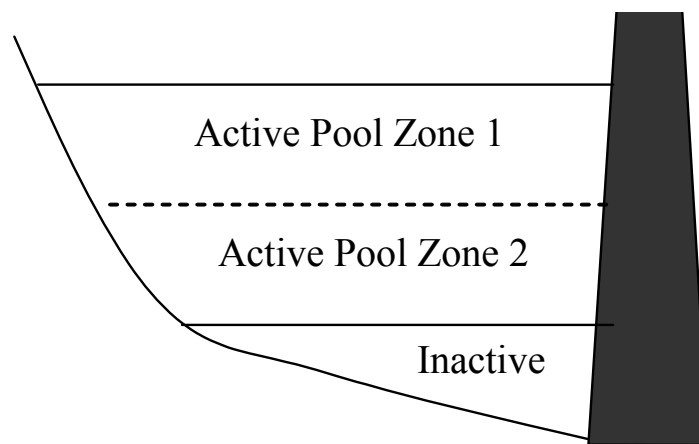


Figure 4.1 Reservoir Pools and Zones

Releases and withdrawals to meet the requirements for a particular right are made from the storage above its inactive pool. A water right has access to the volume of water contained in its active conservation pool adjusted for net evaporation losses. The cumulative total storage below the top of conservation pool is specified in *WS* record field 3.

Any number of water rights can refill storage capacity in the same reservoir and/or make releases from the reservoir to supply diversion, hydropower, or instream flow requirements. The storage capacity entered in *WS* record field 3 is the total cumulative capacity to which the reservoir can be refilled under that right's priority, assuming the reservoir has been drawn down in previous months or by senior rights in the current month and stream flow is now available for refilling.

For reservoirs with multiple rights, the storage capacity specified for each right must equal or exceed the storage capacity specified for more senior rights or else not specify refilling (not be *WR* record type 1). In the water rights priority computational loop sequence, storage capacity can remain the same or be increased but can not be decreased as each more junior right is considered in priority order.



The various quantities computed by the model for a particular water right reflect consideration of all senior rights but not junior rights. In performing computations for a given water right, except for hydropower rights, in a given month, the beginning-of-month and end-of-month storage is not allowed to exceed the storage capacity associated with that right. In order to appropriately determine head, hydropower rights allow the beginning- and end-of-period storage to exceed the storage capacity of the hydropower right due to other junior rights at the same reservoir.

### **Multiple Reservoir System Operations**

In modeling multiple-reservoir systems, rules are required for *SIM* to determine amounts to release each month from each of the alternative reservoirs. If two or more reservoirs are associated with a water right, an operating rules *OR* record following each *WS* record defines the multiple-reservoir operating rules. An *OR* record can also be provided for a single secondary reservoir associated with a water right, if needed to either specify the control point location or to flag pipeline conveyance. The *OR* record includes the reservoir control point location, storage capacity at top of zone 2, zones 1 and 2 release ranking factors, and specification of gravity flow versus pipeline flow.

All of the operating rule parameters entered on *OR* records have default values that are activated if the *OR* record field is blank or if there is no *OR* record. Without *OR* records, multiple-reservoir system release decisions are based on releasing each month from the reservoir that is most full in terms of percentage of active conservation storage capacity.

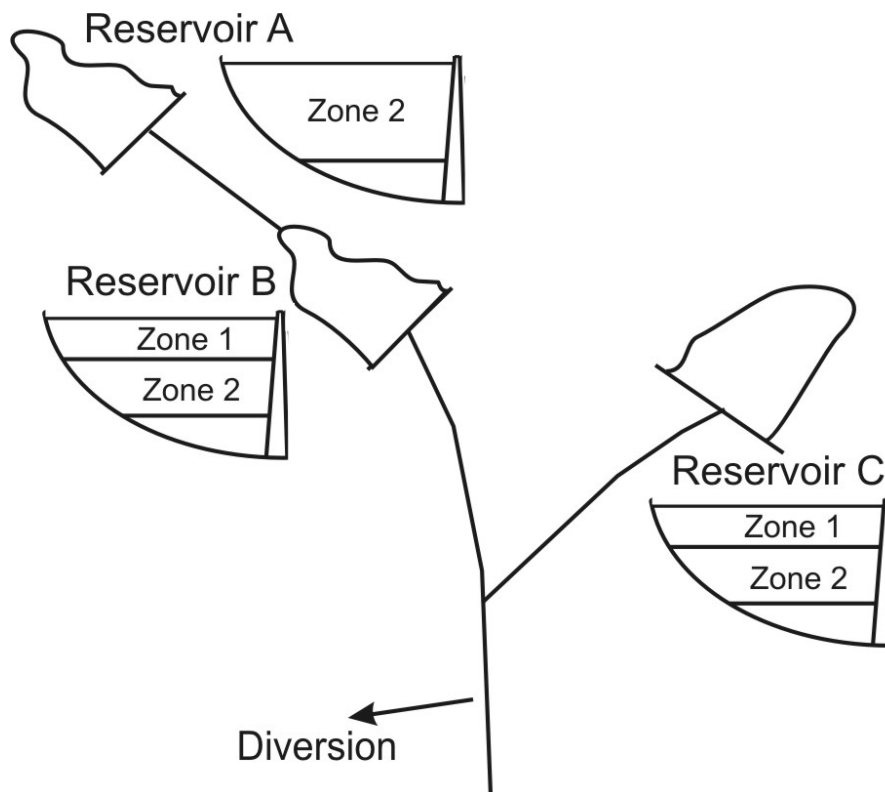


Figure 4.2 Storage Zones for Defining Multiple-Reservoir Release Rules

The model-user defines operating rules by *OR* record entries of values for zone 1 and zone 2 cumulative storage capacities and ranking factors for each of the two zones for each reservoir. As illustrated by Figures 4.1 and 4.2, the active pool is divided into two zones for developing multiple-reservoir operating rules. Zone 1 is the portion of the active pool above a designated elevation. Zone 2 is the remainder of the active storage capacity lying below zone 1. Zone 1 can be eliminated by specifying its cumulative capacity as equal to that for zone 2. Zone 2 may be eliminated by specifying its cumulative capacity as equal to the inactive storage capacity. Multiple reservoir release decisions are based on balancing the storage, as a percent of zone capacity, in each reservoir.

In each time step of the simulation, reservoir storage balancing within a particular zone is based on computing a ranking index for each reservoir in the system as follows, with the release that month being made from the reservoir with the greatest value of the index.

$$\text{rank index} = (\text{multiplier factor}) \left[ \frac{\text{storage content in zone}}{\text{storage capacity of zone}} \right] + \text{addition factor} \quad (4.2)$$

Equation 4.2 can be written more concisely as:

$$\text{rank index} = M \left[ \frac{\text{content}}{\text{capacity}} \right] + A \quad (4.2)$$

where  $M$  denotes the factor entered in *OR* record fields 4 and 5 for zones 1 and 2, respectively, and  $A$  is the factor entered in *OR* record fields 7 and 8. The defaults are 1.0 for the *multiplier factor*  $M$  and 0.0 for the *addition factor*  $A$ . *OR* records are not required if defaults are adopted for all fields of the record. The content/capacity fraction computed each month for each reservoir varies between 0.0 and 1.0.

Zone 1 must be empty in all the reservoirs in the system, in order for releases to be made from zone 2 of any of the reservoirs. If only one reservoir has water in zone 1, the release will come from that reservoir. If two or more reservoirs have water in zone 1, Equation 4.2 is used to compute a ranking index for each of the reservoirs. The release is made from the reservoir that has the greatest value for the index. If zone 1 is empty in all reservoirs, the same selection procedure is applied based on the storage contents of zone 2 of each reservoir. If the release results in the zone 1 storage being emptied for that reservoir while other reservoirs still have water in zone 1, the release is limited to that required to empty zone 1 in that reservoir. Additional releases are made, as required, from zone 1 of one or more other reservoirs. The reservoirs are not precisely balanced since, in each month, only one selected reservoir releases for the water right, unless the release depletes the storage capacity of the zone or reaches the release limit. A maximum allowable monthly release limit for a reservoir may be specified on the *OR* record.

The secondary reservoirs eligible to release from a storage zone for a water right are ranked according to the rank index computed with Equation 4.2. If the values of the *multiplier factor*  $M$  and *addition factor*  $A$  of Equation 4.2 entered on the *OR* records are the same for all the reservoirs, the operating rule simply balances the percentage depletion of either zone 1 or zone 2 of each reservoir. The *OR* record weighing factors  $M$  and  $A$  allow some reservoirs to be emptied faster than others. If  $M$  is 0.5 and 1.0 for Reservoirs A and B, respectively, and  $A$  is the same for both

reservoirs, the storage content of Reservoir A, expressed as a fraction (ranging from 0.0 to 1.0) of zone capacity, must be at least twice that of Reservoir B in order for the release to be made from Reservoir A. Likewise, if  $M$  is the same for both reservoirs, and  $A$  is 0.0 and 0.5 for Reservoirs A and B, respectively, the storage content of Reservoir A, expressed as a fraction of zone capacity, must be greater by 0.5 than Reservoir B in order for the release to be made from Reservoir A.

*JO* record field 7 allows selection between two options regarding the storage to use in the multiple reservoir release decision computations: (1) the beginning-of-period storage or (2) the intermediate end-of-period storage at that point in the water rights priority loop computations, which is subject to change due to more junior water rights.

#### Gravity Flow in River Channels versus Pipeline/Canal/Pump Conveyance

By default, reservoir operation is based on assuming conveyance by gravity flow in river channels. Reservoir releases can meet diversion requirements at the control point of the reservoir or at any control point located downstream of the reservoir. *OR* record field 6 is used to remove the gravity flow constraint. A pipeline or canal, with pumps as needed, is assumed to convey water from the reservoir to the control point of the water right diversion, which can be any location.

#### Releases for Downstream Senior Rights

Reservoirs located upstream of a diversion are assumed to make direct releases to supply the diversion requirement. The pump/pipeline/canal option activated by *OR* record field 6 allows diversions from a reservoir to be conveyed to any control point. However, without the pump/pipeline/canal option, reservoirs that are physically able to release only to control points that are downstream of the diversion location may still contribute to system operations. These reservoirs, referred to as *downstream* reservoirs, are limited to mitigating stream flow depletions made by senior rights downstream of the diversion location. The amount of water that a *downstream reservoir* may release is limited to the flow that has been passed through the diversion location to meet senior water right requirements as illustrated by the following example.

Figure 4.3 illustrates a system composed of four reservoirs and one diversion, which is subject to the constraint of another more senior water right. The system diversion can be met from stream flow depletions at control point CP-4 and releases from reservoirs RES-A, RES-B, RES-C, and RES-D located at control points CP-1, CP-2, CP-3, and CP-5. Since reservoir RES-D at control point CP-5 is not located upstream of the system diversion location at control point CP-4, its role is limited to minimizing the adverse impacts on water availability of the senior right at control point CP-6. In each month of the simulation, the computations include determination of the amount of water to release from each subcomponent of the four-reservoir system to meet the diversion at CP-4, based on balancing storage depletions in the reservoirs.

The multiple reservoir system release rules may involve interactions with other more senior rights in the river basin. For example, the senior right at control point CP-6 in Figure 4.3 is not part of the four-reservoir/one-diversion system but impacts the water available to the system. The model maintains an accounting of the amount by which the senior right at CP-6 reduces water availability at the other control points and allows releases to be made from reservoir RES-D, as well as RES-A,

RES-B, and RES-C, to mitigate this amount. Therefore, to this limited extent, reservoir RES-D contributes to meeting the permitted system diversion at CP-4 and maintaining storage in the system reservoirs, even though RES-D is not located upstream of CP-4. Likewise, reservoir RES-A can contribute to refilling storage in RES-B and RES-C, and vice versa, in a similar manner.

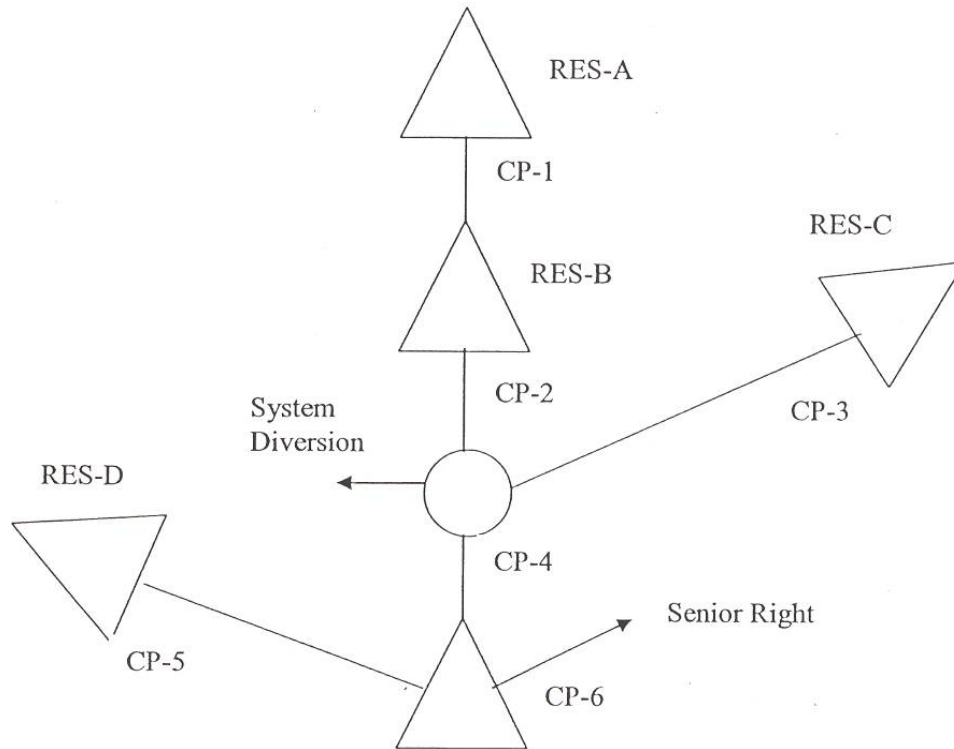


Figure 4.3 Multiple Reservoir System

In this example, water is conveyed only by gravity flow in the stream channels. However, *WRAP-SIM* includes optional capabilities for simulating pump/pipeline/canal systems. For example, water could be conveyed by pipeline from reservoir RES-D to control CP-4 to contribute to the system diversion. If appropriately flagged in *OR* record field 6, reservoir RES-D will be treated just like reservoirs RES-A, RES-B, and RES-C in making multiple-reservoir releases to meet the system diversion at CP-4, even though RES-D is not located upstream of CP-4.

Again using the system in Figure 4.3 as an example, the three upstream reservoirs RES-A, RES-B, and RES-C are able to release directly to the system diversion location at CP-4. Downstream reservoir RES-D is not. Naturalized stream flows at control points CP-4 and CP-6 are 20 ac-ft and 30 ac-ft, respectively. The senior right diversion and storage refilling requirement at CP-6 is 17 ac-ft. The system diversion requirement at CP-4 is 25 ac-ft.

The senior right stream flow depletion of 17 ac-ft reduces the available stream flow to the system diversion to 13 ac-ft, resulting in 12 ac-ft to be released from system reservoirs. Of the 20 ac-ft of inflow to CP-4, 7 ac-ft were passed through the control point to meet the senior right diversion. This amount is the maximum that RES-D may release for the system diversion.

Effectively, it is releasing the 7 ac-ft to the senior right, freeing that amount of water for use by the system diversion. Of course, any of the upstream reservoirs RES-A, RES-B, and RES-C may release all of the 12 ac-ft if the storage content is sufficient.

The downstream release constraint is determined on a control point basis. If a second system diversion exists at control point CP-4 that is junior to the first, the amount that RES-D may release for the second system diversion is constrained by the amount that RES-D released for the first. If RES-D released 4 ac-ft for the first system diversion, then it is limited to releasing 3 ac-ft for the second because a total of 7 ac-ft were passed through the control point to the senior water right. *SIM* maintains an accounting of depletions at and releases to each control point as well as an accounting at each control point of releases made from downstream reservoirs to determine the downstream releases constraints. Negative incremental inflows may cause inaccuracies in the flow accounting.

### **Iterative Reservoir Volume Balance Computations**

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

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

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

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

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

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

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

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

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

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

### **Multiple Rights Associated with the Same Reservoir**

Any number of diversion, hydropower generation, or instream flow requirements may be supplied from the same reservoir. A particular reservoir may be assigned to any number of water rights. Storage may be refilled to different levels by multiple rights connected to a reservoir. A particular right may refill storage, divert/release from storage, or both. A reservoir may be the primary reservoir for several rights and a secondary reservoir for other rights.

The water use requirements for each right associated with a reservoir are supplied from the total active storage content of the reservoir below the top of conservation pool of that right regardless of how the reservoir is refilled. An inactive storage capacity may be specified for each right, from which withdrawals can not be made for that right. However, storage capacity associated with a reservoir is not otherwise allocated among multiple rights in *SIM*. Thus, a senior right may replenish storage depleted by a junior right in previous months. A junior water right could empty its

active storage pool, even though the depleted storage capacity affects water available to a senior right at the same reservoir during the next month. However, as discussed below, this issue may be addressed by modeling a shared multiple-owner reservoir as multiple separate reservoirs.

### Modeling a Single Reservoir as Multiple Reservoirs

Two or more river authorities, water districts, cities, or other entities may share the same reservoir. If the owners all have equal access to the total storage shared in common, their water use may be aggregated and the reservoir modeled as a single reservoir using the basic *WR* and *WS* record features. However, the reservoir operation problem is more complicated if each entity individually owns or contractually controls a specified portion of the storage capacity in the one reservoir. If each owner has a dedicated storage capacity from which the other owners are not allowed access, the multiple-owner reservoir may be treated as multiple separate reservoirs located at the same control point. Each component reservoir has its own storage capacity, diversion/release targets, and operating rules.

If nonlinearities of the area-volume relationship used in the evaporation computations are not of concern and if the different owners can be assigned different priorities, a single reservoir with multiple owners can be modeled as separate reservoirs easily within *SIM* without having to activate additional special computational methods. However, with net evaporation-precipitation modeled as a nonlinear function of storage, a scheme for its allocation among the multiple reservoir owners is required. Priorities or an alternative allocation scheme are also required to define the order in which the multiple owners have access to inflows to fill their storage and meet their water use requirements. The evaporation allocation *EA* record facilitates allocating the net evaporation-precipitation volumes among the otherwise computationally separate reservoirs. If the rights share the same priority, *AF* record parameters are also provided to allocate available stream flow.

*SIM* can automatically handle the allocation of the total net evaporation volume between multiple component reservoirs without needing the *EA* record evaporation allocation routines if the following two premises are accepted as being valid.

1. The storage versus area relationship defined by either the *SV/SA* record table or the coefficients on the *WS* record is linear. The storage versus area relationship adopted for each component reservoir is a linear relationship representing the actual single reservoir.
2. The evaporation volume is allocated between the different entities in direct proportion to their beginning-of-month and end-of-month storage contents.

The *EA* record evaporation allocation routine allows a nonlinear storage-area relationship for the actual reservoir to be applied to each of the individual component reservoirs representing different owners and allows specification of alternative strategies for allocating evaporation.

### Evaporation Allocation Methodologies Activated by the EA Record

The multiple *computational* reservoirs representing each entity's share of the storage capacity in the single actual reservoir are listed on an evaporation allocation *EA* record along with selection of allocation method. The *computational* reservoirs listed on an *EA* record represent the multiple storage components of the single actual reservoir.

Each component reservoir listed on an *EA* record must be associated with a type 1 or 7 right that refills storage in that reservoir. The evaporation allocation routine is applied only to type 1 or 7 rights. However, any number of type 2, 3, 5, or 6 rights or *IF* record rights may also withdraw or release water from the reservoir. Thus, the evaporation allocation may be associated with essentially any reservoir operating scenario. With multiple rights at the same reservoir, evaporation computations are repeated in the water rights loop priority sequence, with the last computed evaporation volume replacing amounts determined as more senior rights were considered. Thus, the *EA* record evaporation allocation should be performed with the most junior right at each component reservoir, which must be type 1 or 7 rights, controlling the refilling of storage.

Total net evaporation-precipitation volume is computed based on the total area determined as a function of total storage content. Total storage determined by summing the contents of the component reservoirs is combined with a storage-area relationship to obtain the water surface area. Although not required by *SIM*, component reservoirs will normally share the same storage versus area relationship (*SV/SA* records) in the model. A component reservoir's share of the evaporation-precipitation volume is computed by one of the alternative methods listed below.

- Option 1. *Incremental Based on Water Right Priorities*.- As the water rights are considered in priority order, the most senior right with a reservoir on the *EA* record is allocated the net evaporation computed prior to considering the other junior rights. Each subsequent water right with a reservoir on the *EA* record is allocated its incremental additional net evaporation in the priority sequence. The concept is to determine evaporation unaffected by junior rights in the priority sequence.
- Options 2 and 22. *Proportional to Storage Content*.- The evaporation-precipitation volume is allocated among the component reservoirs in proportion to beginning-of-month storage. If the beginning-of-month storage is zero in all reservoirs, net evaporation associated with refilling during the month is divided equally between the reservoirs. Options 2 and 22 are the same except for the last reservoir.
- Options 3 and 33. *User-Specified Factors*.- The net evaporation-precipitation volume is allocated among the component reservoirs based on multiplier factors entered on an *EF* record. Thus, the model-user defines a fixed proportion for each reservoir. The computations switch to option 2 above if beginning-of-month storage drops below a limiting level specified on the *EF* record. The difference between options 2 and 3 is that the multiplier factors for option 2 are the ratio of beginning-of-month storage content to storage capacity and for option 3 are specified on an *EF* record. Options 3 and 33 are identical except for handling of the last reservoir.
- Option 4. *Priority Adjusted with Multiplier Factors*.- The net evaporation volume is first determined in the same manner as option 1 and then multiplied by a factor from the *EF* record. The computations switch to option 2 above if the beginning-of-month storage drops below a limiting storage level specified on the *EF* record. With factors of 1.0 and no switching limit, option 4 is identical to option 1.

Method (option) 1 models the fundamental principle of a prior appropriation water right priority system. The method 1 computations are based on accumulating storage and evaporation



volumes as the simulation progresses through the priority sequence. Component reservoirs associated with junior rights in the priority sequence are not considered when determining the evaporation for a particular more senior water right. Method 4 is a variation of method 1 providing additional flexibility for adjusting the allocation.

Methods 2, 22, 3, and 33 consist of multiplying an estimate of the total net evaporation-precipitation volume by a computed or given factor for each reservoir. With methods 2 and 22, *SIM* computes the factors as the ratio of beginning-of-month storage in each component reservoir to the total for all the reservoirs. With methods 3 and 33, the model-user provides the factors on *EF* records. Options 22 and 33 are identical to options 2 and 3 except for the feature described below.

Since the evaporation allocation computations occur in the water rights priority sequence, end-of-month storage for junior rights has not yet been computed when a particular more senior right is considered. Net evaporation-precipitation volumes are always computed in *SIM* based on an average water surface area determined from both end-of-month and beginning-of-month storage. End-of-month storage is a function of net evaporation, which is a function of end-of-month storage. Thus, an iterative algorithm is required. The evaporation allocation algorithm is integrated into the normal iterative computational procedure described earlier in this chapter for simultaneously determining reservoir outflow, net evaporation, and end-of-month storage volumes. However, in applying the storage-area relationship to determine water surface area, the best estimate of end-of-month storage at that point in the priority sequence calculations is used for the allocation algorithm. For any component reservoir for which end-of-month storage has not yet been computed, the end-of-month storage is estimated as the beginning-of-month storage. In order to ensure that the combined total net evaporation volume is correct, for methods 2 and 3 defined above, the volume for the last reservoir listed on an *EA* record is computed as the final correct total net evaporation-precipitation volume less the amounts previously determined for the other reservoirs.

This option 2 and 3 feature for forcing the evaporation for the component reservoirs to sum to the correct total is not applied with options 22 and 33. With options 22 and 33, all component reservoirs listed on the *EA* record are treated the same, and thus the evaporation volume for the component reservoirs will typically not sum to the correct final total.

With method 1, the correct total evaporation is computed at each point in the priority sequence and the incremental evaporation assigned to the right is determined by subtracting the cumulative incrementals previously assigned to senior rights. Thus, the evaporation for the component reservoirs automatically sum to the correct total. The problem associated with options 22 and 33 that is described in the preceding paragraph is also pertinent to option 4.

#### *Multiple Rights at the Same Component Reservoir*

The following are key basic concepts in combining multiple rights at the same component reservoir listed on an *EA* record. With multiple water rights at the same reservoir, diversions and releases associated with senior rights are accumulated in memory and incorporated into the water budget computations associated with the other more junior rights at that same reservoir. In the water right priority sequence simulation, the water accounting computations for a particular water right includes consideration of the diversions and releases at

the same reservoir previously determined for more senior rights. However, the evaporation and end-of-month storage volumes previously computed for any senior rights at the reservoir are not considered. Net evaporation and end-of-month storage volumes are computed again from scratch as each right is considered in the priority sequence. Total hydroelectric energy generation is also recomputed from scratch for multiple hydropower rights at the same reservoir.

The following routines are applied in the water rights simulation when considering a water right located at a reservoir listed on an *EA* record.

1. For type 1 and 7 rights (*WR* record field 6), the net evaporation-precipitation volume is computed based on evaporation allocation methods activated by the *EA* record options outlined in the preceding two pages. The evaporation allocation methods are applied only to type 1 and 7 rights.
2. For hydropower rights, the head used in the hydropower computations corresponds to the summation of the storage contained in all of the component reservoirs listed on the *EA* record. Likewise, the elevation of the bottom of the power pool refers to total storage capacity summed for all the reservoirs. Storage in all *EA* record reservoirs is summed in the computation of head and specification of bottom of power pool for all hydropower rights. However, the *EA* record evaporation allocation routines are not applied for hydropower rights. Evaporation is determined by the conventional *SIM* routine.
3. The stream flow availability allocation routine activated by the *AF* record is applied to all water rights associated with all reservoirs listed on the *EA* record. Storage and evaporation are not relevant to the *AF* record stream flow availability routine.

The *EA* record evaporation allocation routines are activated within *SIM* only for type 1 and 7 rights. However, with caution, any number of water rights of any of the types can be applied at *EA* record reservoirs. Evaporation allocation options 2, 3, 22, and 33 are different than options 1 and 4 in regard to dealing with multiple rights at the same component reservoir.

Reservoir storage is filled only by types 1, 5, and 7 rights (*WR* record field 6). Thus, with or without *EA* records, every reservoir must have at least one type 1, 5, or 7 water right or the reservoir will never refill. Typically, with multiple rights at the same reservoir, the most junior right will be a type 1 right that performs the final refilling in the priority sequence. Likewise, for *EA* record reservoirs, the final evaporation allocation typically will be determined with a type 1 right at each reservoir listed on the *EA* record.

Since with or without *EA* records, type 2 and 3 rights do not refill storage, the final end-of-month storage is yet unknown, and evaporation volumes are approximate. Since type 2 and 3 rights do not activate the *EA* record routine, water surface areas determined from the nonlinear storage-area relationship are approximate. The degree of inaccuracy depends on the nonlinearity of the storage-area relationship. This evaporation volume is used only in the determination of the amount of water available to the right from reservoir storage. The evaporation affects the diversion only if the reservoir empties. The actual final evaporation volume for the reservoir should be determined later in the priority sequence in association with a type 1 right that activates the *EA* record evaporation allocation routine.

Likewise, the evaporation volume computed for hydropower rights is approximate, but serves only in the determination of the amount of water available to the hydropower right from reservoir storage if followed in the priority sequence by a type 1 or 7 right. However, as a separate issue for hydropower rights, *SIM* uses the total storage summed for all the *EA* record reservoirs in the determination of head and minimum power pool elevation.

Evaporation allocation options 1 and 4 are based on incremental evaporation volumes. With options 1 and 4, storage and evaporation volumes are accumulated. The evaporation computed for the most senior component reservoir treats the other junior component reservoirs as not existing. Thus, there must be a priority sequence with one type 1 or 7 water right at each *EA* record reservoir. For example, with three reservoirs listed on an *EA* record, there must be exactly three type 1 or 7 water rights representing the three reservoirs. There can not be two type 1 rights at the same reservoir interrupting the priority sequence storage and evaporation volume accumulation. There can be any number of complete sets of three type 1 or 7 rights as long as there is no intermingling between the sets of three rights in the priority sequence. Any other types of rights at the *EA* record reservoirs should be senior to the type 1 and 7 rights driving the evaporation allocation algorithm. These option 1 and 4 requirements are not applicable for options 2, 22, 3, and 33.

Options 2 and 3 use the last reservoir listed on the *EA* record to assure that the evaporation for the component reservoirs sum to the correct total for the actual real reservoir. Thus, a type 1 or 7 right junior to all the other rights associated with the *EA* record reservoirs must be assigned to the last reservoir listed on the *EA* record. This requirement is not applicable to options 22 and 33. Options 22 and 33 are the most flexible of all the evaporation allocation options in dealing with multiple rights at the same component reservoirs.

#### Allocation of Available Stream Inflow to the Reservoirs

Water right priority numbers set the order in which rights are considered in the computations and thus have access to available stream flow. However, two or more of the reservoir owners may share the same priority. With multiple rights having the same priority, an alternative methodology is adopted to allocate available flow between water rights. The *AF* record serves this purpose. With the *EA/AF* record option activated, the amount of stream flow available to a water right is determined in the water rights priority loop computations as follows. If the parameters *MIN* and *MAX* are not used, the algorithm consists simply of multiplying the available stream flow by the factor *AFX* from the *AF* record.

- The available stream flow volume ( $A_1$ ) is first determined in the normal manner and then adjusted by the *AF* record parameters as follows.
- If the minimum limit (input parameter *MIN*) is not zero, the adjusted available stream flow is set at  $A_1$  as long as  $A_1$  does not exceed *MIN*.
- If  $A_1$  exceeds *MIN*, an input multiplier factor *AFX* is applied as follows
$$\text{adjusted available stream flow} = \text{MIN} + (A_1 - \text{MIN}) \times \text{AFX}$$
- If maximum limit (input parameter *MAX*) is not zero, the adjusted available flow is set at *MAX* if the volume computed by the equation above exceeds *MAX*.

The *AF* and *AX* records both serve the same purpose and are based on the same simulation algorithm. The stream flow availability allocation factors *AFX* record connected to the *EA* record is designed for modeling multiple-owner reservoirs. The flow availability *AX* record connected to the priority circumvention *PX* record discussed in the last section of this chapter can be more generically applied to any water right. The *PX/AX* option allows allocation factors to vary monthly throughout the year, while the *EA/AF* option is limited to a constant factor for the entire year.

### **Water Supply Diversions**

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

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

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

In the *SIM* simulation, in the water rights priority loop, diversion requirements are satisfied to the extent allowed by available stream flow and reservoir storage. A diversion shortage is declared any time the diversion target can not be fully met. A diversion shortage is computed as the monthly target described in the preceding paragraphs less the computed actual diversion amount as limited by water availability. The priority number sets the seniority of the diversion relative to other rights. A diversion requirement may be run-of-river with zero storage. Alternatively, a diversion requirement may be met by stream flow supplemented by releases from one or more reservoirs.

### **Return Flows**

Return flows can represent water discharged back into the stream after use, such as municipal and industrial wastewater treatment plant effluent or irrigation return flows. Return flows can also represent water transported through conveyance facilities such as canals, pipelines, and pumping plants from other control points which may be located any place. The control points of origin and destination of the diversion return flow can be located in different river basins. Intrabasin or interbasin transfers may be simulated in this manner. Alternatively, such transfers of water may

also be modeled as a type 4 right (*WR* record field 6) or by using the alternate control point (*SO* record), pipeline (*OR* record), or constant inflow (*CI* record) options described elsewhere in this chapter. Transient right XP option 1 on the *PX* record allows return flows computed as a function of actual diversion amounts to have a priority that is different than the diversion. Return flow priorities affect the order in which other water rights have access to the return flow.

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

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

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

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

The variable *RFMETH* entered as either 0, 1, 2, 3, or 4 in *WR* record field 7 specifies the return flow method adopted for the water right as follows.

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

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

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

### **Other Inflows and Outflows**

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

The constant inflow/outflow (*CI* record) option allows input of 12 flows, for the 12 months of the year, associated with a specified control point. This option may be used to model:

- return flows not otherwise included in the return flow options, such as return flows from water supply withdrawals from groundwater aquifers
- diversions not otherwise included in the water rights
- channel losses not otherwise included in the channel loss option
- interbasin transfers of water to the control point
- interactions between groundwater and stream flow associated with aquifer pumping

Sets of 12 inflows may be entered for any control points on pairs of constant inflow *CI* records. An outflow is entered as a negative value of inflow. The constant inflows are added to the flows at the control point designated on the *CI* record and at all control points located downstream. If channel loss factors are input on pertinent *CP* records, the *CI* record inflows/outflows are adjusted by channel losses at downstream control points.

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

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

### **Hydroelectric Energy Generation**

Hydroelectric energy production rights are similar to diversion rights in *WRAP-SIM*. Both hydropower (types 5 and 6) rights and diversion (types 1, 2, and 3) rights are activated with a water right *WR* record. An energy generation target is entered on the *WR* record for a hydropower right. Reservoir storage and hydropower operation information is specified on *WS* and *HP* records. A reservoir storage volume versus water surface elevation table (*PV/PE* records) and constant tailwater elevation (*HP* record) or tailwater elevation versus discharge table (*TE/TQ* records) are input to allow the model to compute head.

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

Energy generation target, actual production, and shortage amounts may be written to reservoir/hydropower project and/or water right output records. If only one hydropower right is associated with a particular reservoir/hydropower plant, the energy amounts are the same on the reservoir/hydropower and water right output records. With multiple hydropower rights at the same reservoir/hydropower project, the multiple water right output records contain the cumulative energy amounts associated with each water right. The reservoir/hydropower project output record shows the cumulative energy amount associated with the most junior hydropower right at the reservoir.

For each period of the simulation, the energy production target is met as long as sufficient water and head is available from stream flow and reservoir storage. An energy shortage occurs if sufficient water is not available to meet the user-specified energy requirement. The model also computes secondary or surplus energy. Secondary energy represents additional energy, above the specified energy target, that potentially could be generated by passing reservoir releases for downstream diversions through the turbines. Only reservoir releases for water rights senior to the hydropower right are considered in computing secondary energy. Secondary energy is treated by

the model as a *negative* energy shortage. No releases from storage or stream flow depletions are made if previous releases for senior rights are sufficient to meet or exceed the energy requirement.

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

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

### Input Data for Hydropower Rights

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

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



### Energy Equation and Multiplier Factor

Hydroelectric energy computations are based on the following equations:

$$E = P t \quad (4.3)$$

$$P = \gamma Q H e \text{ (unit conversion factors)} \quad (4.4)$$

$$E = \gamma Q H e t \text{ (unit conversion factors)} = Q H e t (POWFCT) \quad (4.5)$$

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

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

P – power generated [Watt (W) = Nm/second; MW = 1,000,000 W = 1,000 kW;  
horsepower = 550 ft-lb/s = 0.7457 kW]

$\gamma$  – unit weight of water [lb/ft<sup>3</sup>, kN/m<sup>3</sup>]

Q – discharge through turbines during time period [ac-ft/month; 10<sup>3</sup> m<sup>3</sup>/month]

H – head [feet, meters]  
= mean reservoir water surface elevation for period minus tailwater elevation

e – plant efficiency [dimensionless]

t – time period (one month)

*POWFCT* = power factor used in *WRAP-SIM*

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

$$E = Q H e t (POWFCT) \quad (4.6)$$

where: 
$$POWFCT = \gamma \text{ (unit conversion factors)} \quad (4.7)$$

*POWFCT* is a multiplier factor that reflects unit conversions and the unit weight of water. Values of *POWFCT* for several alternative sets of units are tabulated in Table 4.3 and may be computed for any other set of units. *SIM* uses a default *POWFCT* of 0.0010237 corresponding to the units shown in the last column of Table 4.3. Thus, the default *POWFCT* = 0.0010237 automatically used by *SIM* is appropriate if the variables are expressed in the following units:

$$\begin{aligned} POWFCT &= 0.0010237 \\ \text{energy (E) in megawatt-hours (MW-hrs)} \\ \text{discharge (Q) in acre-feet/month} \\ \text{head (H) in feet} \end{aligned}$$

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

Table 4.3  
Hydropower Factor for Alternative Sets of Units

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

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

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

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

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

As noted in Table 4.3, the value for *POWFCT* is 2.7222 if the following units are adopted: flow volume for period t in 1,000 cubic meters (10<sup>3</sup> m<sup>3</sup>), head in meters (m), and energy in kiloWatt-hours (kW-hrs).

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

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

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

#### System Operating Rules for Hydroelectric Power

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

Hydroelectric power production can be included in multiple reservoir system operations. Hydroelectric power can be generated only at a primary reservoir. Energy can be generated at a

hydroelectric plant as a type 5 or 6 right using flows from releases from multiple reservoirs. A run-of-the-river hydropower right is modeled as a type 5 water right with the total storage capacity equal to the inactive capacity.

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

Because the energy produced is a function of both the flow through the turbines and the average head on the turbines, hydropower rights are handled differently than diversion rights in regard to assumptions regarding refilling reservoir storage. The non-hydropower convention of ignoring storage above the storage capacity of the water right in a multiple-right reservoir is not applicable to hydropower. A type 5 hydropower right will make stream flow depletions and receive releases from secondary reservoirs to meet its energy requirement as well as refill storage up to its storage capacity. If the storage in the reservoir is above the capacity of the right, the right will make stream flow depletions and reservoir releases necessary to just maintain the storage level while meeting the energy requirement. The target stream flow depletion is computed as the additional water that must be passed through the hydropower turbines assuming that the end-of-period storage is either the water right storage capacity or the current storage level, whichever is higher, plus the amount needed to refill storage. The actual energy produced must be computed in an iterative manner if the reservoir is drawn-down by releases through the turbines since the monthly release volume required depends on head but head depends on the release volume.

#### Multiple Hydropower Rights at the Same Reservoir

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

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

## Instream Flow Requirements

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

Instream flow targets are determined step-by-step within *SIM* following the procedure outlined earlier in this chapter in the section entitled *Setting Diversion, Instream Flow, and Hydropower Targets*. The target setting procedure is addressed further in the *Users Manual*. Instream flow targets are specified in a *SIM* input file using an instream flow *IF* record and supporting water use coefficient *UC*, drought index *DI/IS/IP*, target options *TO*, supplemental options *SO*, flow switch *FS*, target series *TS*, reservoir storage *WS*, and multiple-reservoir operating rules *OR* records. An *IF* record is required for each instream flow requirement. The other optional auxiliary records activate various options. Any number of *IF* records may be input for a particular control point, with the next more junior instream flow target replacing the latest more senior target in the priority-based water rights computational loop.

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

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

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

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

### Reservoirs Associated with IF Record Rights

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

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

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

### Interactions Between Hydropower and Instream Flow Rights

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

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

### Special Conditions

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

Instream flow limits are normally compared to the total regulated flow at specified locations in determining water available to junior water rights. However, an option is activated by *IF* record field 7 that allows the instream flow limits to be compared to regulated flows

exclusive of reservoir releases made from upstream reservoirs to meet water rights requirements at locations further downstream. This option allows modeling of situations in which reservoir releases for other purposes are not given credit for contributing to instream flows between the dam and downstream point of diversion.

### Specification of Instream Flow Requirements

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

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

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

### Types of Instream Flow Computations

The computational method associated with a particular instream flow requirement is specified as variable *IFMETH* in *IF* record field 7. *PASS2* entered in *JO* record field 10 allows a second pass to be activated regardless of *IFMETH*. Otherwise, the options are as follows.

- 0, 1 Junior rights are curtailed as necessary to meet the instream flow requirements during a single pass through the water rights loop. The minimum instream flow (regulated flow) targets result in constraints on the amount of water available to junior rights. At any point in priority sequence, regulated flow reflects only the effects of senior rights.
- 2 Junior rights are curtailed as necessary to meet instream flow requirement during a second pass through the water rights loop. The first pass through the water rights loop is

used to compute regulated flows and instream flow shortages without limiting the amount of water available for other rights. The second pass is made only if at least one instream flow failure (shortage) occurs during the first pass.

- 2 Junior rights are curtailed as necessary to meet instream flow requirements during both the first and second passes through the water rights loop.
- 3 Option 3 is the same as Option 1 except reservoir releases are used as necessary to meet instream flow requirements. Option 3 requires that a reservoir storage *WS* record follow immediately behind the *IF* record. The *WS* record may be followed by *OR* records.
- 4 Option 4 is the same as Option 2 except reservoir releases are used as necessary to meet instream flow requirements. Option 4 requires that a reservoir storage *WS* record follow immediately behind the *IF* record. The *WS* record may be followed by *OR* records.
- 4 Option -4 is the same as Option -2 except reservoir releases are used as necessary to meet instream flow requirements.

Example - Set of Records Specifying Instream Flow Requirements

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

```

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

```

Water is allocated to all *IF* and *WR* rights in turn, in priority order, as the simulation proceeds through the water rights loop for January of the first year. Instream flow requirement *IF2* at control point *CP15*, with a priority date of 1 August 1972 (19720801) is the most senior of the rights shown and therefore the first to be considered. Multiplying the annual instream flow target of 5,200 ac-ft/yr by a January distribution factor of 0.0 results in a January target of zero.

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

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

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

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

#### Multiple IF Record Rights at the Same Control Point

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

#### Instream flow Computations

*IF* record instream flow targets are set within the *SIM* water rights priority sequence in essentially the same manner as *WR* record diversion and hydropower targets, but the targets are used differently. The amount of water available to a *WR* record right is determined based on unappropriated and regulated flows at the control point of the right and downstream control points. *IF* record instream flow targets are minimum limits on regulated flows used in defining water availability for junior *WR* record rights. For each month of the simulation, the *SIM* instream flow routines perform the following tasks. The *IF* record field 6 *IFMETH* options for which the tasks are relevant are shown in parenthesis.



- Setting the Instream Flow Target for the Month (Options 0, 1, 2, 3, and 4)

*SIM* determines the monthly instream flow target following the procedures previously outlined based on information entered on *IF*, *UC*, *DI/IS/IP*, *TO*, *FS*, *SO*, and/or *TS* records. An instream flow target is determined the same way as a diversion target and expressed in the same units as a diversion target, such as acre-feet/month or other volume/month units.

- Writing Instream flow Shortages to the Output File (Options 0, 1, 2, 3, and 4)

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

- Initial Pass through Water Rights Loop (Options 2 and 4)

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

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

- Second Pass through Water Rights Loop (Options 2 and 4)

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

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

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

- *Second Pass through Water Rights Loop (Options -2 and -4)*

*IF* record field 6 *IFMETH* options –2 and –4 in combination with *PASS2* from the *JO* record provide variations of the procedure allowing curtailment of junior rights in all months regardless of conditions and always requiring a second pass. These options provide capabilities for experimentation on the effects of the instream flow algorithms.

- *Single Pass through Water Rights Loop (Options 1 and 3)*

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

- *Reservoir Storage for Meeting Instream flow Requirements (Options 3 and 4)*

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

Instream flow shortages are determined in the water rights loop. Whenever the instream flow target exceeds the monthly regulated flow at a control point, a shortage is computed as the instream flow target minus the regulated flow. For an *IF* record right with reservoir storage (option 3 or 4), the instream flow shortage is mimicked as a diversion right with return flow factor of 1.0. The 100 percent return flow occurs at the same control point as the dummy diversion (instream flow shortage). Thus, if an instream shortage occurs, a diversion target equal to the shortage is created, and the corresponding return flow factor is assigned a value of 1.0. The *IF* record right is then processed through the water right computations just like a *WR* record right. The simulation results recorded in the *SIM* output file for *IF* record and *WR* record water rights can be compared in Table 5.3 of Chapter 5. The reservoir release, storage, and net evaporation volumes are non-zero for instream flow output records only for *IF* record rights with *IFMETH* option 3 or 4.

### Regulated Flows and Instream Flow Targets

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

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

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

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

### Actions to Prevent or Reduce Instream flow Shortages

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

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

### Single Versus Dual Passes through the Water Rights Computational Loop

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

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

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

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

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

An erroneous instream flow shortage could possibly occur in a situation in which a diversion right actually increased regulated flows in the first pass but is curtailed in the second pass. Consider a diversion downstream of the instream flow target control point made from releases from a reservoir located upstream. The reservoir release increases the regulated flow at the instream flow target control point prior to being diverted downstream. For purposes of reducing instream flow shortages, this particular diversion right should not be curtailed. The model-user can handle this situation by bracketing the *WR* record in the input file with *IF*

records, with the same priority as the diversion right, that turn the instream flow requirement off and then back on again just before and after consideration of the *WR* record right.

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

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

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

### **Dual Simulation Options**

The dual simulation feature is designed primarily for applications where multiple rights with different priorities divert water from the same reservoir system. Without the dual simulation, reservoir draw-downs associated with junior diversions may be inappropriately refilled in subsequent months by senior rights at the same reservoir. The set of dual simulation options allow stream flow depletions computed during an initial simulation to be used as upper limits constraining depletions during a second simulation. Selected water rights may be switched on or off during either the initial or second simulations. Dual simulations may be performed automatically during a single execution of *SIM*. Alternatively, *SIM* may be executed once to develop a set of stream flow depletions, which are then incorporated into a *SIM* input file as time series *TS* records for use in further simulations.

The dual simulation feature is discussed in the next section from the perspective of its application as a priority circumvention mechanism. Logistics of its use are outlined as follows.

The dual simulation options are activated for individual water rights as specified by either *SO* record field 14 or *PX* record field 2. A default dual option may be set for all rights in *JO* record field 11, subject to being over-ridden for individual rights by the *SO* or *PX* records. The options available for application to one or any number of water rights are as follows.

- Option 1: The water right is activated only during the initial simulation.
- Option 2: The water right is activated only during the second simulation and is not subject to an initial simulation stream flow depletion constraint.
- Option 3 with variations 33 and 333: A dual simulation is automatically performed. Stream flow depletions computed during the first simulation serve as upper limits on water availability during the second simulation. The stream flow depletions computed during the initial simulation may optionally be written to the message file.
- Option 4: The water right is activated only during the initial simulation. A stream flow depletion array is developed. If an option 5 right follows this right, the depletions serve as upper limits on water availability for the option 5 right during the second simulation. The stream flow depletions may optionally be written to the message file.
- Option 5 with variations 55 and 555: A dual simulation is performed with this water right being activated only during the second simulation. The stream flow depletion array from the preceding option 4 right serves as an upper limit on depletions for this option 5 right.

A second simulation is automatically performed if and only if option 3 or 5 is selected for one or more rights. Alternatively, the simulation may be performed once to develop a set of stream flow depletions, which are then incorporated into an input file as *TS* records for use in further simulations. Options 3 and 4 depletions may also be written to the message file.

With dual options 3 and 5, stream flow depletions each month for a right determined during the first simulation serve as a maximum limit on stream flow depletions during the second simulation. The stream flow depletion for a given month during the second simulation is not allowed to exceed the depletion for that month occurring during the initial simulation. Options 33, 333, 55, and 555 are variations of options 3 and 5 that allow the depletion constraints to be relaxed somewhat by allowing flexibility in the timing of the depletions.

Dual options 33 and 55 are the same as options 3 and 5 except the constraints applied during the second simulation are based on cumulative stream flow depletions rather than depletions in each individual month. For any month, for a particular right, the total cumulative stream flow depletions since the beginning of the second simulation can not exceed the corresponding cumulative depletions occurring in the initial simulation.

With options 333 and 555, for water rights that refill reservoir storage (types 1 and 7 rights described in Chapter 5), the limit during the second simulation is the accumulative stream flow depletions since the reservoir was last full. During the second simulation, the accumulation of initial simulation depletions is zeroed any time the reservoir contents are full to capacity. For other water right types, the options 333 and 555 limits applied during the second simulation are the first simulation depletion for the current month plus any excess depletion from the immediately preceding month. Unused stream flow depletions below the constraining limits are carried into the next month but no further.

## Options for Circumventing the Priority Sequence

As discussed throughout this manual, the *WRAP-SIM* modeling strategy is based on simulating water management/allocation/use in a priority-based water rights loop computational sequence. In general, senior rights affect the amount of water available to junior rights but are not affected by the junior rights. However, in some applications, various needs may arise for evading the priority sequence. For example, as previously discussed, same-month return flows from water supply diversions from storage associated with a junior right are not available to senior rights located downstream but should be. The next-month diversion return flow option is designed to address this issue. Likewise, the next-month hydropower option allows senior rights access to hydropower releases. Second pass instream flow *IF* record options involving a repeat of the water rights loop within a given month are discussed in the preceding section.

Multiple rights with the same priority, agreements that subordinate a senior right to a junior right, reservoir storage priority complexities, and various other aspects of water management may motivate circumvention of the water right priority loop sequencing in the simulation computations. Four different sets of options activated by the priority circumvention *PX* record and stream flow availability factor *AX* record are designed to facilitate evasion of the normal *SIM* priority sequence based allocation of available water. The options may also serve other purposes not necessarily related to evading the restrictions of the priority system. The different *PX* record options may be applied either independently or in combination with each other and combined with various other *SIM* features. Strategies for their use are governed by the water management situation being modeled and the ingenuity and creativity of the model-user.

The *PX* record described in the *Users Manual* provides the following four different types of modeling features which are described by the remainder of this chapter.

1. The dual simulation feature is actually designed to contribute to maintaining the priority system though discussed here in the context of priority circumvention applications. A set of dual simulation options allow a repeat of the simulation for the entire hydrologic period-of-analysis. Water rights may be selected for activation or deactivation during either the first or second simulation. [*JO* record field 11, *PX* record field 2, or *SO* record field 14]
2. For multiple rights sharing the same priority, the allocation of available stream flow may be based on parameters provided as input. [*PX* record field 3 and *AX* record]
3. All downstream control points are normally considered in both determining the amount of water available to a water right and adjusting water availability for the effects of the right. A downstream control point limit option allows the model-user to adjust the manner in which these computations cascade downstream. [*PX* record fields 4 and 5]
4. Transient priority *XP* options allow a computational water right to be activated and deactivated at different points in the priority sequence. The simplest *XP* option allows a return flow to occur later in the priority sequence than the corresponding

diversion. A second more complex XP option allows all features of a water right to be activated and deactivated at different points in the computational sequence based on two different assigned priorities. [*PX* record fields 6–12]

### Dual Simulation Feature

The *SIM* dual simulation feature described in the preceding section of this chapter allows stream flow depletions determined during an initial simulation to serve as upper limits on flow depletions during a second simulation. Selected water rights may be activated or deactivated during either of the two simulations. Dual simulations may be performed automatically during a single execution of *SIM*. Alternatively, *SIM* may be executed once to develop a set of stream flow depletions, which are then incorporated into a *SIM* input file as time series *TS* records for use in further simulations. The basic concept of the dual simulation feature is to establish a set of stream flow depletions for selected water rights during an initial simulation representing a specified water management scenario, which then serve as upper limits on the stream flow available to those rights during a second simulation reflecting an altered or different water management scenario.

The *SIM* dual simulation options activated by the *PX* record were originally motivated primarily by applications where multiple rights with different priorities divert water from the same reservoir. The dual simulation feature is designed to preserve the priority system by preventing actions of junior rights in a current month from adversely affecting more senior rights in future months through the delayed affects of reservoir storage draw-downs and refilling. Without the dual simulation options, reservoir draw-downs associated with junior diversions may be refilled in subsequent months by senior rights at the same reservoir. For example, junior diversion right XX draws the reservoir down in July. During August, senior right YYY at the same reservoir refills storage with stream flow that otherwise would have supplied other third-party rights with priorities falling between the priorities of senior right YYY and junior right XX. Thus, the diversion by junior right XX from reservoir storage in July results in other senior third-party rights having stream flow availability inappropriately reduced in August and later months when senior right YYY refills the reservoir.

With activation of the dual simulation option, an initial simulation is made without junior right XX to determine the proper stream flow depletions during each month of the period-of-analysis for senior right YYY. The dual simulation option allows the senior right YYY stream flow depletions computed during the initial simulation without junior XX to be used as upper limits constraining senior right YYY depletions during a second simulation in which junior right XX is also activated. An additional junior *WR* record may also be added to allow senior right YYY to further refill storage with excess flows not appropriated by any other rights.

### Allocation of Available Stream Flow

A fundamental concept of *WRAP-SIM* is that available stream flow is allocated to each water right in turn in the water rights computation loop priority sequence. Since the computational procedure is based on considering water rights one at a time, for purposes of sequencing rights in the computations, no two rights can be assigned the same priority.



However, water rights actually having the same priority and located at the same control point or different control points with access to approximately the same stream flow may be modeled as adjacent rights in the priority sequence with the available stream flow allocated between them based on user-specified parameters entered on the *PX* and *AX* records.

Water right priorities govern access to available stream flow. However, when multiple water rights have the same priority, another strategy must be adopted to allocate available stream flow between the rights. The *PX* record stream flow availability allocation option uses multiplier factors. Either a constant multiplier factor may be entered on the *PX* record or factors for each of the 12 months of the year may be entered on *AF* records. The amount of stream flow available to a right is first determined in the normal manner and then multiplied by the pertinent factor from the *PX* or *AX* record. The model-user must select appropriate multiplier factors.

For example, consider a water management situation in which three *WR* record diversion and/or storage rights located at the same control point have equal access to available stream flow. One-third of the available flow is to be allocated to each water right. The three rights are assigned priorities allowing them to be adjacent in the priority sequence. The most senior right is assigned a multiplier factor of 0.33333 on the *PX* record, allowing it access to one-third of the available stream flow. The second right is assigned a factor of 0.50 allowing it access to half of the remaining two-thirds of the available stream flow. The most junior of the three rights is assigned a factor of 1.0 allowing it access to the remainder of the available stream flow.

The methodology is explained in the *Users Manual*. The same available stream flow allocation procedure is also implemented by an *EA/AF* record option described earlier in this chapter in the section on multiple rights associated with the same reservoir.

#### Downstream Control Point Limit

As outlined in Figure 2.2 and discussed in Chapter 2, the *SIM* simulation is organized based on a water rights priority loop embedded within the monthly time step loop. Within the water rights priority loop, as each individual water right is considered in turn, the computations are performed in four stages.

- Task 1: A water supply diversion, hydropower generation, or other type of target is set.
- Task 2: The amount of stream flow available to the right is determined. Stream flow availability is determined as the lesser of the stream flow availability array amounts at the control point of the water right and at each of the control points located downstream.
- Task 3: Water volume balance computations are performed to compute the stream flow depletion, net reservoir evaporation, end-of-period storage, return flow, diversion and diversion shortage, and hydroelectric energy generated and shortage.
- Task 4: The stream flow availability array values at the control point of the water right and at downstream control points are decreased by a flow depletion and increased by a return flow or hydropower release, with adjustments for channel losses or loss credits.

The simulation begins with the stream flow availability array consisting of naturalized flows at each control point. The array of flows is adjusted (task 4) for the effects of each water right in turn. At any point in the priority sequence, the stream flow availability array provides an account of the volume of flow still available after considering all rights that are more senior.

Task 1 consists of determining the amount of stream flow that is available to the water right. For example, assume that junior water right JJJ located at control point CP-1 in Figure 4.4 is being simulated in the priority sequence. The volume of stream flow available to right JJJ is the lesser of the amounts in the stream flow availability array at control points CP-1, CP-3, CP-4, and CP-5. Stream flow depletion by senior right SSS at CP-4 may have resulted in the available flow at CP-4 and/or CP-5 being less than at CP-1. This means that all or a portion of the flow at CP-1 has already been committed for senior right SSS. Junior right JJJ does not have access to that flow at CP-1 and must let it pass through.

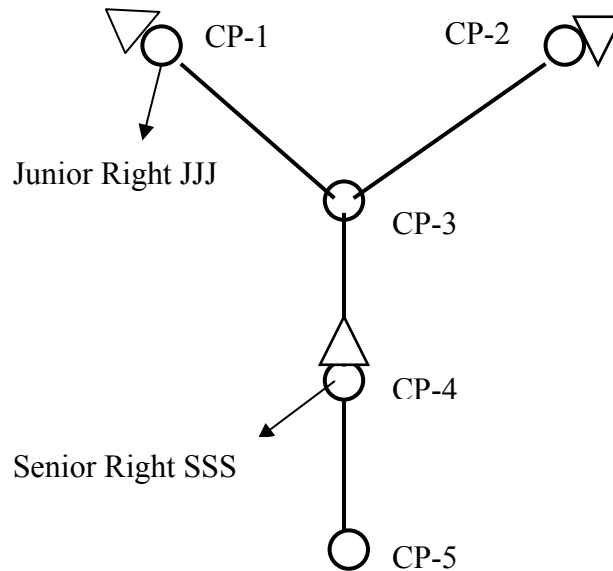


Figure 4.4 System Schematic for Example 10 in Appendix B

The purpose of the *PX* record control point limit option is to circumvent the basic concept of stream flow availability being affected by flows at all downstream control points. The feature may be used to model the removal of requirements for pass-through of flows for downstream senior rights. The control point limit option alters tasks 2 and 4. Without this option, the control point of the water right and all downstream control points are considered in tasks 2 and 4. The option is activated by specifying a control point located downstream of the control point of the water right. This control point and any control points located downstream are removed from consideration in task 2. Task 4 adjustments to the stream flow availability array at and below the *PX* record control point are also altered.

The control point identifier *XCPID* is entered on the *PX* record associated with a particular water right. The water right of the *PX* record is not constrained by the effects of any

other water rights on flows at *XCPID* and other control points located downstream of *XCPID*. As the water right is modeled in the priority sequence, the simulation computations are altered in the following two ways.

1. Control point *XCPID* and control points downstream of *XCPID* are not considered in determining stream flow availability (Task 1). An increase *XAV* in the amount of stream flow available to the right may result. An option limits the maximum increase in available stream flow to not exceed flow depletions by senior rights at *XCPID*. Optionally, only *XCPID*, not other downstream control points, may be excluded in the determination of stream flow availability.
2. The increase in stream flow depletion, with appropriate channel loss adjustments is omitted in the Task 4 adjustments of the stream flow availability array at control point *XCPID* and at control points located downstream of *XCPID*.

Increases in water availability *XAV* each month are written to the *SIM OUT* file. *XAV* is zero unless flows at or downstream of *XCPID* are controlling stream flow availability for the right in that month. If flows at or downstream of *XCPID* are controlling stream flow availability, ignoring the control point results in an increase in water availability which may result in an increase in the stream flow depletion by the water right.

The *PX* record control point limit feature will work with any of the negative incremental flow options specified in *JD* record field 8, but caution should be exercised if applied with options 1 or 5. The *PX* record feature is based on the following basic concept. The effects of senior water rights are the reason that stream flow availability for a water right may be governed by flows at downstream control points in some months. Physically, the water right may have to curtail depletion of stream flow so that flows available to downstream senior rights are not reduced. With negative incremental flow options 2, 3, or 4, senior rights are the only reason for stream flow availability to be controlled by flow at downstream control points rather than at the control point of the water right. However, with negative incremental flow options 1 and 5, negative incremental naturalized flows may also affect stream flow availability for water rights located upstream. Option 5 may particularly complicate the simulation in this regard.

The manner in which the *PX* record control point limit options are applied depends on the particular water management situation being modeled and the preferences of the modeler. For example, as discussed above, the feature may be used to prevent stream flow available to an upstream junior right from being diminished by a subordinated senior right. This particular type of application and modeling strategy are discussed below. Other types of applications are possible as well.

#### *Combining Features to Model a Subordination Agreement*

Example 10 of Appendix B illustrates the following general modeling strategy in which *PX* record control point limit and dual simulation features and a *BU* record backup right are combined to simulate a subordination agreement. Referring to Figure 4.4, water right JJJ at control point CP-1 is junior to water right SSS at CP-4. However, a subordination agreement has been executed stating that contrary to the normal prior appropriation water right permit system in

effect in general, as an exception, water right JJJ is not required to curtail diversions or storage to pass inflows through its reservoir to maintain stream flows for senior right SSS. The agreement is not applicable to the other water rights at various locations in the river basin, some of which have priorities falling between those of senior right SSS and junior right JJJ.

With CP-4 specified for *XCPID* on the *PX* record for junior right JJJ, its stream flow availability is not affected by the requirement to pass flow through CP-1 for senior right SSS at CP-4. Since in the model senior right SSS has already made its stream flow depletion, junior right JJJ is appropriating water that is not available. Thus, there is an excess appropriation. In performing task 4, *SIM* omits the portion of the junior right JJJ stream flow depletion that is an excess appropriation, adjusted for channel losses, from the stream flow availability array adjustments at and below the *PX* record control point *XCPID*.

Thus, the *PX* record control point limit option allows junior right JJJ to appropriate stream flow without being constrained by senior right SSS. Stated more precisely, junior right JJJ is not constrained by the effects of any other water rights on flows at CP-4 and the downstream CP-5. However, a problem occurs in that the junior right JJJ stream flow depletion may include an amount over the volume of stream flow that is actually available. The excess stream flow depletion amount at CP-1 is reduced by channel losses to an equivalent amount at CP-4. The strategy described below for dealing with the excess stream flow depletion uses the backup right option activated by a *BU* record. With reservoir storage associated with senior right SSS, the dual simulation option may also be activated to protect other water rights.

A new water right is created for the sole purpose of serving as a backup right to account for the excess stream flow depletion *XD2*. The backup right is junior to junior right JJJ, is located at control point CP-4, and diverts from the same reservoir as senior right SSS. If storage is sufficient, the *XD2* results in a draw-down of the reservoir. Otherwise, a diversion shortage is declared which represents a diversion shortage to be incurred by senior right SSS. A *BU* record backup right normally adds a shortage incurred by another right to its target. However, with a *BU* record combined with the *PX* downstream control limit activated for a right, *WRAP-SIM* adds the excess stream flow depletion, instead of shortage, to the target of the backup right.

Assume the procedure outlined above results in a drawdown in reservoir storage in June to mitigate the junior right JJJ excess stream flow depletion. This means that a certain volume of stream flow was appropriated by junior right JJJ at CP-1 rather than passing the flow on down to senior right SSS. Thus, senior right SSS's reservoir is lower than it would have been otherwise at the end of June. Other rights not bound by the subordination agreement may be affected when senior right SSS refills its reservoir in July or some later month. This is the complexity discussed in the prior section describing the dual simulation feature. The dual simulation feature is activated to address this concern. An initial simulation without the *PX* record control point limit feature and *BU* record backup feature activated establishes a sequence of stream flow depletions for senior right SSS that serve as upper limits in the second simulation.

Application of the dual option may possibly limit access of water right SSS to unappropriated stream flows. A *WR/WS* record type 1 reservoir refilling right junior to all other rights may be added to capture any remaining available flow at the end of the priority sequence.

The strategy for modeling this particular type of subordination agreement situation is summarized as follows.

- Step 1: The *PX* record control point option prevents the stream flow available to an upstream junior right from being diminished by a subordinated senior right located downstream.
- Step 2: Step 1 above may result in an increase in stream flow depletions by the upstream junior right that must be mitigated by the subordinated senior right. A junior backup *BU* record right is created for this purpose. The incremental addition in stream flow depletion by the junior right is treated as a diversion target by the backup right. The backup right may supply its diversion target from the reservoir of the subordinated senior right. Diversion shortages incurred by the backup right are treated as diversion shortages associated with the subordinated senior right.
- Step 3: Step 2 above may result in drawdown of reservoir storage in the reservoir of the subordinated senior right. Refilling during future months may inappropriately affect other rights that are not connected to the subordination agreement. The *PX* record dual simulation capability is adopted to deal with this complexity.
- Step 4: Step 3 could result in constraining the filling of the senior right's reservoir more than necessary. There could possibly be unappropriated stream flows to which the senior reservoir is inappropriately denied access. This problem may be partially addressed by adopting dual simulation options 33, 333, 55, and 555 described in Chapter 2. Alternatively, an extra right junior to all other pertinent rights may be added solely to refill storage with any unappropriated stream flow that may still be available after considering all relevant water rights.

The strategy outlined above for modeling subordination agreements is designed to prevent third-party rights from being affected, including by actions in a current month causing effects in future months through reservoir storage draw-down and refilling. However, other aspects of the simulation may still result in third-party rights being affected. Next-month return flows and next-month power releases circumvent the priority sequence. Next-month return flows and next-month power releases associated with rights either connected or unconnected to the subordination agreement rights may cause third-party rights to be affected by the subordination. Target setting options applied for third-party rights based on stream flows or storage likewise complicate the simulation in this regard.

The objective of the strategy outlined above is to model agreements between certain parties to circumvent the priority system without affecting other water users (third-parties) in the river basin. The difficulty is that in complex real-world river/reservoir systems, water management actions have unintended consequences. Modeling studies may very well involve attempts at preventing effects on third parties in the simulation model that can not be prevented in the real world. Thus, these types of modeling strategies must be applied with caution.

### Transient Water Right Options

The *PX* record transient water right features provide additional capabilities for circumventing the water right priority sequence. A *WR/PX* record combination creates a pair of computational water rights. The first and second components of the water right duo are assigned priorities from *WR* field 5 and *PX* field 8, respectively. The *PX* record activates two types of dual switching priority (*XP*) water rights. The first type assigns a priority to return flows that is different than the diversion priority. The second involves activation and deactivation of an entire water right at different points in the priority sequence.

With *XP* option 1, return flows may occur at points in the priority loop sequence different than the corresponding diversion. This option may be used to control which other rights have first access to return flows based on the priority placement of the return flows. The second internal component right does nothing but the return flow. If the return flow priority entered in the *PX* record is junior to the priority in the *WR* record, the return flow occurs in the same month as its diversion. Otherwise, the return flow occurs in the next month which is the next time its priority is reached in the priority based simulation computations.

*PX* record *XP* option 2 is motivated by subordination agreements designed to evade the priority system. A computational right is activated and deactivated at different points in the computations based on assigned priorities. The objective is to constrain water availability for other rights bracketed by the two priorities. A right is activated based on the senior priority from its *WR* record. Its stream flow depletion, return flow, and storage change are later reversed automatically within the model as a second component right at a priority from the *PX* record. Stream flow depletions are returned to the stream as return flows. Return flows are reversed as stream flow depletions. In typical subordination applications, the actual water right will be modeled with another *WR* record with its actual junior priority. The mechanisms of applying these options are explained in the *Users Manual*.



## CHAPTER 5 ORGANIZATION AND ANALYSIS OF SIMULATION RESULTS

This chapter describes the *WRAP-SIM* simulation results recorded in the OUT, SOU, and DSS output files and the further organization and analysis of the *SIM* output with the program *TABLES*. The OUT file is accessed with *TABLES*. The SOU and DSS files store the same simulation results output data as the OUT file but in different formats, neither of which are read with *TABLES*. The YRO, ZZZ, BES, BRS, and HRR files are other special purpose *SIM* output files that are discussed in Chapter 6. Whereas Chapter 5 covers the main simulation results stored in the OUT, SOU, and DSS files and organized with *TABLES*, Chapter 6 covers the simulation results provided in the other auxiliary *SIM* output files.

Simulation results are typically extremely voluminous. The role of the post-simulation program *TABLES* is to convert the extensive time series of *SIM* simulation output data into meaningful information. *TABLES* also provides capabilities for converting the simulation results into formats that facilitate further organization and display with Microsoft Excel, HEC-DSSVue, and ArcGIS. *TABLES* reads *SIM* input and output files, computes reliability and frequency metrics, performs various other data manipulations, and develops a variety of tables and data tabulations. Although *TABLES* also contains options for tabulating *SIM* input data, its primary role is organizing, analyzing, summarizing, and displaying simulation results. Chapter 4 of the *Users Manual* provides instructions for using *TABLES*.

Programs *SIM* and *TABLES* and their combined application are addressed in this *Reference Manual* and this chapter. As discussed in the *Supplemental Manual*, program *TABLES* also provides similar capabilities for organizing, analyzing, summarizing, and displaying programs *SIMD* and *SALT* simulation results.

### **OUT, SOU, and DSS Output Files**

The model-user selects the control points, water rights, and/or reservoir/hydropower projects for which monthly time series of simulation results are to be recorded in the main *SIM* output files, which have filename extensions OUT, SOU, and DSS, following instructions provided in Chapter 2 of the *Users Manual*. Any or all of the three output files are activated with the optional output files *OF* record described in Chapter 3 of the *Users Manual*, with the default being to activate only the OUT file. The OUT, SOU, and DSS files store the same *SIM* simulation results output data, but in different formats.

The OUT file may be created in either text or binary format and is designed to be accessed by program *TABLES* in either format. The default text file version of the OUT file can be read directly with Microsoft Word or WordPad as well as read by *TABLES*. The binary unformatted machine language version of the OUT file activated by the parameter *OUTFILE* on the *JD* record is read only by *TABLES*. The advantages of the binary option are a significant reduction in the size of the OUT file and, for simulations with large amounts of output, a significant reduction in computer execution time. Also, since simulation results are stored on the computer hard drive in the same form as computed by the processor, there is no loss in precision. The data in the text file version of the OUT file are stored with the number of digits to the right



of decimal shown in Tables 5.3-5.5 presented later in this chapter, which results in decreasing precision for small numbers.

Not all editors read the OUT file. All of the WRAP output files that are created as text files, except the OUT file, can be directly read with essentially any editor including either Microsoft NotePad or WordPad. The text version of the OUT file is written by *SIM* in a direct access format designed to be efficiently read by *TABLES*. The OUT file contains line breaks that are read fine by Microsoft WordPad and Word but are not recognized by NotePad.

The *SIM* output SOU file is an ordinary text file read directly with any editor, but is not accessible with *TABLES*. Although the OUT file can also be read directly without *TABLES*, it is designed for efficient data management focused on connecting with *TABLES*. The purpose of the SOU file is to present simulation results in a convenient-to-read columnar format designed to be examined directly with Microsoft WordPad, NotePad, or other editor or to be transported to Microsoft Excel or other spreadsheet program without intervention with *TABLES*.

The *SIM* DSS output file is read with HEC-DSSVue. The Hydrologic Engineering Center (HEC) Data Storage System (DSS) is described in Chapter 1 and discussed further in Chapter 6. DSS files are in a binary format accessible only by DSS software. DSS routines provided by the Hydrologic Engineering Center are incorporated into the WRAP programs allowing creation of and access to DSS files. The purpose for recording the *SIM* simulation results in a DSS file is to allow access to the graphics and data management capabilities provided by the HEC-DSS Visual Utility Engine (HEC-DSSVue). *WRAP-SIM* simulation results are conveniently plotted with HEC-DSSVue. Computational capabilities provided by HEC-DSSVue may also be useful in analyzing *WRAP-SIM* simulation results.

*SIM* simulation results may be stored by *SIM* in their entirety directly as a DSS file. Alternatively, the same output data may be stored as an OUT file and read by *TABLES*. The program *TABLES* also has options for writing the *SIM* simulation results to a DSS file either without modification or after further computational manipulations.

As illustrated in Figure 2.2 of Chapter 2, the *SIM* simulation proceeds month-by-month sequentially through the hydrologic period-of-analysis. A water rights loop is embedded within the monthly time-step simulation loop. Within each month, water rights are simulated in priority order. Water right, control point, and reservoir/hydropower output records are written to the OUT file as the computations proceed by month and within each month by water right. Water right output records are created in the OUT file as each individual right is considered in the priority sequence. Control point and reservoir/hydropower output records are created each month at the completion of the water rights sequence prior to advancing to the next month. The same simulation results data are stored in memory and recorded in the SOU and DSS files at the completion of the entire simulation.

The *SIM* simulation results are time series of monthly amounts for a variety of variables associated with either control points, water rights, or reservoir/hydropower projects. The model-user selects the control points, water rights, and/or reservoir/hydropower projects for which monthly time series of simulation results are to be recorded in the OUT, SOU, and/or DSS files.

## **SIM Simulation Results Variables**

The variables included in the *SIM* simulation results are listed as follows. As discussed in the preceding section, the same output data are stored in different formats in the OUT, SOU, and DSS files. All of the variables are time series of monthly amounts. All are monthly volumes except for monthly evaporation-precipitation depths tabulated with the *TABLES* 2EPD and 2EVR records and reservoir surface elevations associated with the 2WSE record.

As explained in Chapter 4 of the *Users Manual*, program *TABLES* is controlled by input records with 4-character identifiers. The *TABLES* input record identifiers associated with standard time series tables are adopted here to label the *SIM* output variables. The *TABLES* input record identifiers are shown in parenthesis below and are also referenced in the subsequent Tables 5.1–5.5. The *TABLES* time series records cover all of the variables included in the *SIM* OUT file and two other variables computed from the OUT file data. Most of the *SIM* output variables are incorporated in various other types of tables created by *TABLES* as well.

The SOU (filename extension SOU) output file consists of tables for either control points, water rights, and/or reservoirs, with the first two columns being the year and month and the remaining columns being each of the time series variables. Table headings in the SOU file include the identifiers shown in parenthesis below without the initial numeral 2. The identifiers are also incorporated in the DSS record pathnames when the data are stored in a DSS file. These time series data stored in a DSS file (filename extension DSS) can be tabulated, plotted, and otherwise manipulated with the program HEC-DSSVue.

### **Stream Flow at a Control Point**

naturalized flows (2NAT) – Inflows to the river system at each control point are either read by *SIM* from *IN* records or DSS records or computed within *SIM* with the flow distribution methods described in Chapter 3. The inflows are typically developed by adjusting gaged flows to represent natural hydrology and are thus called naturalized flows. The *SIM* water rights simulation converts naturalized stream flows to regulated and unappropriated flows.

regulated flows (2REG) – Regulated stream flows are the actual sequence of physical stream flows at a control point after all the water rights are allocated their water.

unappropriated flows (2UNA) – Unappropriated flows are uncommitted flows still remaining after all the water rights are allocated their water. Unappropriated stream flows may be less than regulated flows due to instream flow requirements at the control point and requirements for passing flows through the control point for water rights located downstream.

### **Changes in Channel Loss in the Reach Downstream of a Control Point**

channel loss (2CLO) – Channel loss adjustments based on loss factors entered on *CP* records for a river reach below a control point as defined in Chapter 3 and the Appendix A Glossary. Channel losses are losses of return flows, hydropower releases, and other inflows.

channel loss credits (2CLC) – Channel loss credits based on loss factors on *CP* records for the river reach below a control point. Channel loss credits are adjustments applied in determining effects on downstream flows resulting stream flow depletions occurring upstream.

### Specific Components of Regulated Flow at a Control Point

return flows (2RFR) – Return flows returning at this control point are the summation of return flows from all diversions that reenter the stream system at this control point. Reservoir releases for hydropower, releases from storage for downstream instream flow requirements, and water right type 4 inflows are also treated as return flows and included in this variable.

releases (2URR) – This portion of the regulated flow consists of the summation of releases from reservoirs located at this control point and upstream control points that were made to meet water right requirements at other control points located downstream. The releases are from secondary reservoirs located upstream of diversion, hydropower, or instream flow rights.

control point inflows (2CPI) – The 2CPI record data are the total monthly inflow to a control point excluding releases from secondary reservoirs located upstream of the control point for diversion or hydropower rights that are located downstream. Inflows to a control point are not included in the OUT file but rather are computed within *TABLES* by combining other variables from the OUT file. The 2CPI inflow is computed by adding the stream flow depletion (2DEP) at the control point to the regulated flow (2REG) less secondary reservoir releases (2URR). If there are no water rights at the control point or downstream control points that have secondary reservoirs located upstream of the control point, the 2CPI inflow represents the total actual inflow at the control point. The inflow includes stream inflows, diversion return flows returned to that control point, and hydropower releases returned to that control point. The inflows referenced in *TO* record fields 5 & 6 and *FS* record field 2 are conceptually the same but are computed at a point within the water right priority sequence. The 2CPI record contains the final values after considering all water rights.

### Reservoir Storage and Net Evaporation Volumes for a Control Point, Right, or Reservoir

storage (2STO) – End-of-month reservoir storage may be for an individual water right, reservoir, or control point. For a reservoir, the storage is the actual total volume of water stored in the reservoir at the end of the month. For a control point, it is the summation of storage for all reservoirs located at that same control point. For a water right, the level to which the individual right filled the reservoir is reported.

net evaporation-precipitation (2EVA) – Reservoir net water surface evaporation less precipitation volume may be the cumulative total for an individual water right or for an individual reservoir. For a control point, the net evaporation-precipitation volume is the summation of final reservoir amounts for all reservoirs assigned to that same control point.

### Water Right Quantities Reported by Right and Also Aggregated by Control Point

stream flow depletion (2DEP) – As defined in Chapter 3 and the Glossary of Appendix A, the stream flow depletion is the amount of water appropriated by a water right to meet diversion requirements and maintain reservoir storage. The amount reported for a control point is the summation of stream flow depletions for all water rights assigned to the control point.

diversion target (2TAR) – A diversion target is set for a water right in a series of steps governed by the *WR*, *UC*, *SO*, *TO*, *TS*, *FS*, *DI*, and other *SIM* input records. *SO* record field 9 specifies

the intermediate or final target and shortage to be written to the OUT file. The diversion target amount reported for a control point is the summation for all water rights assigned to the control point. For an *IF* record right with *IFMETH* 3 or 4 options activating reservoir releases, the target variable is used to store the reservoir release target which is treated the same as a diversion target as described in Chapter 4. This diversion target variable is not applicable for an *IF* record right without reservoir storage (*IFMETH* options 1 and 2).

diversion shortage (2SHT) – The diversion shortage is associated with individual water rights. The amount reported for a control point is the summation of shortages for all water rights assigned to the control point. For an *IF* record right, the shortage is a failure to meet an *IFMETH* option 3 or 4 reservoir release target as described in Chapter 4.

diversion (2DIV) – The actual diversion is not included in the *SIM* output file but is computed by *TABLES* as the target minus the shortage. For an *IF* record right with reservoir storage, the amount reported in the OUT file as the diversion variable is actually release from an *IFMETH* 3 or 4 reservoir as described in Chapter 4. The *TABLES* 2DIV and 2SHT records also create tables for hydroelectric energy. Water right output records include either diversions or hydropower targets and shortages. Control point output records include the summation of diversion targets or shortages but record zeros for hydropower.

#### Hydroelectric Energy Reported on Water Right Output Records

energy target (2TAR) – Either diversion or hydroelectric energy, but not both, may be specified by a water right as the type parameter in *WR* input record field 6. A hydroelectric energy target or diversion target is set for a water right in accordance with *WR*, *UC*, *SO*, *TO*, *DI*, and other *SIM* input records. The target for each right is recorded on a water right output record. Aggregated target amounts are also recorded on control point output records for diversion rights but not for hydropower rights. Reservoir/hydropower output records also include the final accumulative hydroelectric energy target generated by the most junior water right connected to a reservoir. If only one hydropower right is associated with a reservoir, the energy target is the same on the water right output record and reservoir/hydropower output record. However, with multiple rights, the water right output record has cumulative targets and shortages for individual rights. Reservoir/hydropower output records have only the final accumulative hydroelectric energy target for the most junior water right at a reservoir.

energy shortage (2SHT) – Depending on the water right type specified in *WR* record field 6 in the input file, either an energy shortage or diversion shortage, but not both, may be recorded in the OUT file on a water right output record. The hydroelectric energy shortage is reported as a positive energy amount. Secondary energy is reported as a negative amount. Shortages represent shortfalls in meeting an energy target. As discussed in the preceding Chapter 4, secondary energy is the amount greater than the target resulting from releases through the turbines to meet other senior water right requirements. The cumulative energy shortage or secondary energy is associated with individual water rights. Reservoir/hydropower output records also include the final accumulative hydroelectric energy shortage or secondary energy generation by the most junior water right connected to a reservoir.

firm energy generated (2DIV) – The amount of the energy target actually produced is not included in the water right output record but rather is computed by *TABLES* as the target minus the

shortage. Firm energy generated equals target minus shortage. The *TABLES 2DIV* record creates tables of either diversions or hydroelectric energy in the same manner.

#### Additional Variables Recorded Only on Water Right Output Records

instream flow target (2IFT) – Instream flow targets are specified by *IF* input records and supporting input records as described in *Reference Manual* Chapter 4 and *Users Manual* Chapter 3. *SO* record field 9 specifies the intermediate or final target and shortage written to the OUT file.

instream flow shortage (2IFS) – An instream flow shortage is the amount by which the monthly regulated flow volume falls below the instream flow target.

return flow (2RFL) – The return flow volume for this particular water right is the portion of the diversion volume that is returned to the river system following *WR* record specifications.

secondary reservoir releases (2ROR) – Total volume released from secondary reservoirs this month for this water right following *OR* input record multiple-reservoir system operating rules.

available stream flow (2ASF) – The amount of stream flow available to a water right is computed as each right is considered in the water rights priority loop.

increase in available flow (2XAV) – The increase in available stream flow to result from the *PX* record control point limit option described in the last section of Chapter 4. This variable is recorded only if this *PX* input record field 4 & 5 option is activated.

#### Additional Variables Recorded on Reservoir/Hydropower Output Records

energy shortage (2HPS) – Both shortages in firm energy and additional secondary energy are recorded as the same variable in the OUT file. The hydroelectric energy shortage is reported as a positive energy amount. Secondary energy is reported as a negative amount. Shortages represent shortfalls in meeting an energy target. Secondary energy is the amount greater than the target resulting from releases through the turbines for other senior water rights.

energy generated (2HPE) – The actual energy generated represents the portion of the energy target that was supplied. Only the firm energy target, not secondary energy, is included. The hydroelectric energy recorded on the reservoir/hydropower output record is the accumulated total energy generated by the most junior hydropower right associated with the reservoir.

flow depletions (2RID) – Stream flow depletions associated with a reservoir include all the water taken from stream flow to meet water right requirements at the reservoir.

reservoir inflows (2RIR) – Reservoir inflows from other reservoirs consist of releases from secondary reservoirs to meet water right requirements at this reservoir.

releases (2RAH) – Releases from the reservoir that can be used to generate hydropower. The parameter *LAKESD* entered on the *WS* input records of other non-hydropower rights controls whether or not water supply releases from a reservoir can be passed through hydropower turbines. The default option is for hydropower to access water supply releases.

releases (2RNA) – Releases from the reservoir that are not accessible to the turbines for use in generating hydropower as governed by the parameter *LAKESD* entered on the *WS* input record. Diversions for water rights flagged as lakeside do not pass through the turbines.

adjusted net evaporation-precipitation depth (2EPD) – Evaporation-precipitation depths used to compute volumes are based on *EV* records but are subject to adjustments related to runoff from the reservoir site as specified by *JD* record field 10 and *CP* record fields 8 and 9. These are the adjusted net evaporation-precipitation depths.

net evaporation-precipitation depth (2EVR) – These are the monthly net evaporation-precipitation depths read from the *EV* records prior to the adjustments reflected in the 2EPD variable.

water surface elevation (2WSE) – End-of-month reservoir elevations are computed by *SIM* as a function of storage volume by linear interpolation of the *PV/PE* record storage-elevation table. The only use of water surface elevation in the *SIM* simulation is determination of head for hydropower. However, *PV/PE* records may be provided for any reservoir, with or without hydropower, to tabulate water surface elevations for general information.

### Water Right Variables Aggregated by Reservoir or by Control Point

The organization of the *SIM* simulation is outlined in Figure 2.2 of Chapter 2. Most of the water allocation computations are performed within the water rights loop which is embedded within the monthly time step loop. Each water right is considered in priority order in the water right computation sequence. A water right output record is written to the OUT file upon completion of the computations for that individual right. After all water rights have been considered, the control point and reservoir/hydropower output records are created for that month.

Each variable in the *SIM* OUT file is associated with a control point, water right, and/or reservoir/hydropower project. Some data in the simulation results are unique to either water right, control point, or reservoir/hydropower output records. Other data are repeated on two or three of the output record types. In the *SIM* input dataset, any number of water rights may be located at the same control point. Any number of water rights may be associated with the same reservoir. Any number of secondary reservoirs may be assigned to the same water right. Any number of reservoirs may be assigned the same control point. The aggregation of variable values computed for individual water rights to reservoirs and control points is additive for some variables and cumulative as the last value computed for other variables.

End-of-month storage volume and evaporation-precipitation volume are written to all three types of records. If one water right with one reservoir is located at a control point, reservoir storage will be identical on all three records. However, in general, the amounts may be different. With multiple rights at the same reservoir, the total cumulative evaporation-precipitation volume and end-of-period storage is recomputed as each right is considered in the water right priority sequence.

For a water right that refills and/or releases from reservoir storage, an end-of-month storage volume and net evaporation-precipitation volume are computed as the individual right is considered in its turn in the water right loop priority sequence. If other more junior rights share storage in this same reservoir, end-of-month storage and evaporation-precipitation volumes are recomputed two or more times for the same reservoir. The storage and net evaporation volumes computed by *SIM* in the water right priority loop and recorded in the OUT file on water right output records consist of the accumulative totals at the reservoir considering that water right and all junior water rights. Senior rights have not yet entered the simulation computations. The end-of-month storage volume and net evaporation-precipitation volume recorded on the reservoir/hydropower output record are

the final accumulative volumes determined for the most junior water right at the reservoir. The amounts recorded on control point output records are the summation of the final volumes for all reservoirs located at the control point.

Several hydropower rights with different targets and priorities may be located at the same reservoir. However, the energy target set for each right is the total energy target considering that right and all junior hydropower rights at the reservoir. The energy computations are repeated in the water rights loop with releases committed to more senior hydropower rights still available to generate energy. The hydroelectric energy generated by each *WR* record right is the cumulative total energy considering that right and all junior rights. The cumulative energy target and shortage associated with individual rights are recorded on water right output records. Energy recorded on the reservoir/hydropower output record are the final amount generated by the most junior hydropower right at the reservoir. Hydroelectric energy is not reported on control point records.

The diversion targets and diversion shortages recorded on a control point record are the summations for all the diversion rights assigned to the control point. The diversions and shortages on a water right output record are associated with a single *WR* input record. Any number of water rights may make diversions at the same control point. Diversion volumes for individual rights are simply added to obtain the total for the control point.

Naturalized, regulated, and unappropriated stream flows, and channel loss adjustments are recorded only for control points. However, available stream flow for individual rights reported on water right output records are computed by *SIM* based on intermediate values of regulated and unappropriated flows at pertinent points in the water rights priority loop sequence. Stream flow adjustments for channel losses and loss credits are also computed for individual rights and summed to obtain control point totals.

Several of the variables associated with water rights may also be aggregated within *TABLES* by user-specified groups of water rights. The model-user defines the grouping of water rights by entering group identifiers on *WR* input records which are reproduced by *SIM* on water right output records. Volumes for individual rights are added within *TABLES* to obtain totals for the group. The group aggregation is performed within the *TABLES* table building process.

### **Organization of SIM Output OUT File**

The location of the variables in the OUT file output records are summarized in Table 5.1. Each variable is associated with a control point, water right, and/or reservoir/hydropower project. Table 5.1 indicates whether the variables are found on *SIM* output records for control points, water rights, and/or reservoir/hydropower projects. The second column of Table 5.1 lists the *TABLES* time series input record identifiers that create tables, tabulations, or HEC-DSS records for each of the variables. These identifiers are shown in parenthesis in the preceding list of variables. The organization of the OUT file records is outlined in Tables 5.2, 5.3, 5.4, and 5.5.

The OUT file begins with the five lines of information shown in Table 5.2. The one-line header is followed by three title records (*T1, T2, T3*) read from the *SIM* input file. The fifth line contains the five integers defined in Table 5.2. The simulation results are then written in

monthly blocks of data. Within each month of simulation results, output records for user-specified water rights are written first, followed by selected control point output records, followed by the records for selected reservoir/hydropower projects. The monthly data associated with each specified water right, control point, or reservoir/hydropower project are listed in Tables 5.3, 5.4, and 5.5. These records are all optional. The model-user specifies in the *SIM* input file which of the three types of output records and which water rights, control points, and/or reservoirs to include, following procedures outlined in *Users Manual* Chapters 2 and 3.

Table 5.1  
Summary of *SIM* Simulation Results Variables in OUT File Output Records

Variables Recorded in <i>SIM</i> Simulation Results OUT File	<i>TABLES</i> Time Series Input Record	Control Point Output Record (Table 5.3)	Water Right Output Record (Table 5.4)	Reservoir and Hydropower (Table 5.5)
naturalized stream flow	2NAT	CP field 9		
regulated stream flow	2REG	CP field 10		
unappropriated flow	2UNA	CP field 7		
channel loss	2CLO	CP field 12		
channel loss credit	2CLC	CP field 11		
return flow returned here	2RFR	CP field 8		
upstream reservoir release	2URR	CP field 13		
control point inflow	2CPI	field 10 – 13 + 6		
reservoir storage	2STO	CP field 5	WR/IF field 6	R/H field 5
evaporation-precip volume	2EVA	CP field 4	WR/IF field 5	R/H field 4
stream flow depletion	2DEP	CP field 6	WR/IF field 7	
diversion target	2TAR	CP field 3	WR/IF field 4	
diversion shortage	2SHT	CP field 2	WR/IF field 3	
diversion	2DIV	field 3 – field 2	field 4 – field 3	
hydroelectric energy target	2TAR		WR field 4	
energy shortage	2SHT		WR field 3	
firm energy produced	2DIV		field 4 – field 3	
instream flow target	2IFT		IF field 11	
instream flow shortage	2IFS		IF field 12	
return flow for water right	2RFL		WR field 13	
available stream flow	2ASF		WR/IF field 8	
increase in available flow	2XAV		WR field 14	
secondary reservoir release	2ROR		WR/IF field 9	
hydropower shortage	2HPS			R/H field 2
electric energy generated	2HPE			R/H field 3
stream flow depletions	2RID			R/H field 6
inflows from reservoirs	2RIR			R/H field 7
releases useable for power	2RAH			R/H field 8
releases not accessible	2RNA			R/H field 9
adjusted evap-precip depth	2EPD			R/H field 10
evaporation-precip depth	2EVR			R/H field 11
water surface elevation	2WSE			R/H field 12



Table 5.2  
Organization of Main SIM Output File

First Five Records of WRAP-SIM Output File

OUT File from WRAP-SIM (March 2008 Version)  
 TITLE1  
 TITLE2  
 TITLE3  
 YRST NYRS NCPTS NWROUT NREOUT CR1 CR2 CR4

Definition of Variables on Fifth Record

YRST – first year of simulation  
 NYRS – number of years in simulation  
 NCPTS – number of control points in *SIM* output file  
 NWROUT – number of water rights in *SIM* output file  
 NREOUT – number of reservoirs in *SIM* output file  
 CR1 – length of simulation period from *CR* record  
 CR2 – starting month from *CR* record  
 CR4 – multiplier factor for starting storage from *CR* record

Block of Records Repeated for Each Period (Month)

water rights output records (number of records = NWROUT)  
 control point output records (number of records = NCPTS)  
 reservoir/hydropower output records (number of records = NREOUT)

Total Number of Records in WRAP-SIM Output File

number of records = 5 + (12×NYRS) × (NWROUT + NCPTS + NREOUT)

Table 5.3  
Water Right Output Record

Diversion/Storage Rights			TABLES TABLES		Instream Flow Rights	
Field	Variable	Format	Record	Record	Variable	Format
1	year	I4			IF	A2
2	month	I2			month	I4
3	diversion or energy shortage	F11.3	2SHT	2SHT	reservoir release shortage	F11.2
4	diversion or energy target	F11.3	2TAR	2TAR	required reservoir release	F11.2
5	evaporation-precip volume	F11.2	2EVA	2EVA	evaporation-precip volume	F11.2
6	end-of-period storage	F11.2	2STO	2STO	end-of-period storage	F11.2
7	stream flow depletion	F11.2	2DEP	2DEP	stream flow depletion	F11.2
8	available stream flow	F11.2	2ASF	2ASF	available stream flow	F11.2
9	releases from other reservoirs	F11.2	2ROR	2ROR	releases from other reservoirs	F11.2
10	water right identifier	A16			water right identifier	A16
11	group identifier	A8		2IFT	instream flow target	F11.2
12	group identifier	A8		2IFS	instream flow shortage	F11.2
13	return flow	F11.2	2RFL		month	8x,I2
14	increase in available flow	F10.2	2XAV		year	I5

Table 5.4  
Control Point Output Record

Field	Variable	Format	Columns	TABLES
1	control point identifier	A6	1-6	
2	diversion shortage	F11.3	7-17	2SHT
3	diversion target	F11.3	18-28	2TAR
4	reservoir evaporation-precipitation	F11.2	29-39	2EVA
5	end-of-period storage	F11.2	40-50	2STO
6	stream flow depletion	F11.2	51-61	2DEP
7	unappropriated stream flow	F11.2	62-72	2UNA
8	return flows returning here	F11.2	73-83	2RFR
9	naturalized stream flows	F11.2	84-94	2NAT
10	regulated stream flows	F11.2	95-105	2REG
11	channel loss credits	F11.2	106-116	2CLC
12	channel losses	F10.2	117-126	2CLO
13	upstream reservoir releases	F10.2	127-136	2URR

Table 5.5  
Reservoir/Hydropower Output Record

Field	Variable	Format	Columns	TABLES
1	reservoir identifier	A6	1-6	
2	hydropower shortage (+) or secondary energy (-)	F11.3	7-17	2HPS
3	energy generated	F11.3	18-28	2HPE
4	reservoir net evaporation-precipitation vol	F11.2	29-39	2EVA
5	end-of-period reservoir storage volume	F11.2	40-50	2STO
6	inflows to reservoir from stream flow depletions	F11.2	51-61	2RID
7	inflows to reservoir from releases from other reservoirs	F11.2	62-72	2RIR
8	reservoir releases that are accessible to hydroelectric power turbines	F11.2	73-83	2RAH
9	reservoir releases that are not accessible to hydropower turbines	F11.2	84-94	2RNA
10	adjusted evaporation-precipitation depths	F11.4	95-105	2EPD
11	evaporation-precipitation depths	F11.4	106-116	2EVR
12	reservoir water surface elevation	F11.3	117-127	2WSE
13	year	I6	128-133	
14	month	I3	134-136	

Note: The format columns of the tables use Fortran format statement terminology, where data types include character (A for alphanumeric), integer (I), and real (F). A6 refers to a 6-character field reserved for a character variable such as a control point or reservoir identifier. I4 refers to a 4-digit field for an integer (no decimal) number. A real number in F11.2 format may contain up to eleven characters counting decimal point and digits, with two digits to the right of the decimal point.

Simulation results from the example presented in the *Fundamentals Manual* are used for illustration throughout the remainder of this chapter. Table 5.6 reproduces the beginning of the OUT file showing the output records for the two instream flow rights, 28 WR record water rights, eleven control points, and six reservoirs for the first month of the 696-month 1940-1997 simulation.

The OUT file is designed to compactly store the voluminous output data in the order in which it is computed. Water right records are written in order of priority as each water right is considered in the computational loop. Control point output records are in the same order as the CP records in the input file. Likewise, reservoir/hydropower records are in the order that reservoirs are first read in the input file. Examination of the OUT file may be useful occasionally for tracking problems, but the format is not convenient for routinely interpreting simulation results. The SOU file is designed to be much easier for people to read than the OUT file but does not record the output data in the exact order that is computed like the OUT file.

Program *TABLES* provides an array of options for organizing, tabulating, analyzing, summarizing, and displaying the simulation results in a variety of formats. The data in the *SIM* OUT file are incorporated into various tables created by *TABLES* including standard time series tables as well as the other types of tables described later in this chapter. The *TABLES* input records that build standard time series tables for each type of data shown in parenthesis in the preceding list of variable definitions and listed in the second column of Table 5.1, middle columns of Table 5.3, and last column of Tables 5.4 and 5.5.

### Water Right Output Records

Each record provides data for a water right for a given month. The records for all of the water rights are grouped together for a given month. As shown in Table 5.3, the water right output record for an *IF* input record instream flow right is different than the record for a *WR* input record right. The variables are stored in the format indicated by the following Fortran format statements.

*WR* record water rights:   Format (I4, I2, 2F11.3, 5F11.2, A16, 2A8, F11.2, F10.2)  
*IF* record instream flow rights:   Format (A2, I4, 7F11.2, A16, 2F11.2, 8x, I2, I5)

Each *WR* record water right output record contains: year and month, shortage and target, net evaporation-precipitation volume, end-of-period reservoir storage, stream flow depletion by the water right, stream flow available to the right before the stream flow depletion, all water that was released from secondary reservoirs to meet the diversion and/or refill storage, the three identifiers from the *WR* input record, return flows, and an available flow increase generated only in conjunction with a *PX* record option.

The actual diversion volume or hydroelectric production is computed within *TABLES* as the target less the shortage. Depending on the water right type specified in *WR* record field 6 in the input file, either an energy shortage, diversion shortage, or storage shortage, may be recorded in the OUT file on a water right output record. The same variable is used to report both energy shortages and secondary energy. The hydroelectric energy shortage is reported as a positive energy amount. Secondary energy is reported as a negative amount. Shortages represent shortfalls in meeting an energy target. Secondary energy is the amount greater than the target resulting from releases through the turbines to meet other senior water right requirements.



Instream flow rights may include releases from reservoir storage to meet the regulated flow target. The release from storage required to meet the instream flow requirement is recorded in field 4 in lieu of diversion target, and the shortage in supplying the reservoir release is recorded in field 3.

The net evaporation-precipitation volume and end-of-period storage volume in fields 5 and 6 are the values determined prior to considering any other junior rights that are associated with the reservoir. The amounts written for the most junior right at the reservoir are the actual values that occur for the reservoir. Any amounts recorded for senior rights at the reservoir are intermediate values only. The reservoir net evaporation minus precipitation volume is positive if evaporation rate exceeds precipitation and negative if precipitation is greater.

The stream flow depletion in field 7 represents the monthly stream flow volume that the water right appropriated to supply the diversion target, account for reservoir net evaporation-precipitation, and/or refill storage. In months with a negative net evaporation-precipitation depth, the stream flow depletion may be a negative number. In this case, the water right actually makes water available to the river system by catching precipitation that falls onto the reservoir surface.

Releases from other reservoirs in field 9 are from secondary reservoirs to meet the storage and diversion requirements of the right. Releases from the primary reservoir are not included.

#### Control Point Output Records

Control point records for all of the control points included in the OUT file are grouped together for a given month. The 136-character record contains 13 variables stored in the format indicated by the following Fortran format statement.

Format (A6, 2F11.3, 8F11.2, 2F10.2)

As indicated in Table 5.4, each record begins with the control point identifier, sum of the shortages and diversion targets for all diversion rights, evaporation-precipitation and end-of-period storage for all reservoirs, and stream flow depletions for all rights located at the control point. The next four fields contain the unappropriated flow remaining at the control point after all stream flow depletions have been made, the sum of the return flow returned at the control point from the current and previous month, and the naturalized and regulated stream flow. Fields 11 and 12 contain adjustments applied for channel loss credits and channel losses. The last field has the portion of the regulated flow that originates as releases made from reservoirs located at this control point or upstream to meet water right requirements at control points located further downstream.

#### Reservoir/Hydropower Output Records

Each record provides data for a reservoir and/or hydroelectric power plant for a given month. All the reservoir/hydropower records are grouped together for a given period. The variables include energy shortage at the reservoir, energy produced at the reservoir, evaporation-precipitation, end-of-period storage, stream flow depletions made available to the reservoir, releases from other reservoirs made available, releases from the reservoir through the outlet works, lakeside releases from the reservoir, net evaporation-precipitation depths with and without runoff

adjustments, reservoir water surface elevation, year, and month. The 136 character record outlined in Table 5.5 contains 12 variables stored in the following format.

Format (A6, 2F11.3, 6F11.2, 2F11.4, F11.3, I6, I3)

The hydroelectric energy produced at the reservoir in each month is calculated from the average water surface elevation of the reservoir, the tailwater elevation for the most junior hydropower right associated with the reservoir, and the total flow through the outlet works for all hydropower rights and other senior rights. Either a turbine flow capacity may be specified or the power produced may be computed assuming that the turbine capacity is unlimited. Hydropower shortages are calculated as the algebraic difference between energy target and the energy produced. Positive shortage values signify that insufficient water was released from the reservoir to produce the energy requirement of the most junior hydropower right at the reservoir. Negative shortages represent secondary energy that was produced by releases through the outlet works to meet senior water right diversion and storage requirements.

Stream flow depletions include amounts for diversions as well as depletions to refill storage and account for net evaporation less precipitation. Depletions for diversions are assumed to enter a primary reservoir and then are either diverted lakeside or released through the reservoir outlet works. The releases written to a reservoir output record include releases made both as a primary and as a secondary reservoir.

### **Types of TABLES Tabulations**

The *TABLES* input TIN file specifies the tables and/or other types of information to be created and written to the *TABLES* output TOU file. The TIN file records begin with the four character identifiers shown in parenthesis in Table 5.7. Each record activates routines that create sets of tables and/or tabulations in a variety of user-specified formats.

Chapter 4 of the *Users Manual* explains *TABLES* types 1, 2, 3, and 4 input records and resulting output tables or listings. The *Supplemental Manual* provides instructions for applying *TABLES* types 5, 6, 7, and 8 options. The following general description of types 1, 2, 3, and 4 features is followed by a more in depth presentation of capabilities provided by *TABLES* type 2 options for organizing and analyzing *SIM* simulation results.

Type 1 input records activate routines that read the main *SIM* input DAT file and organize selected data. The IREC routine simply lists *SIM* input records of user-selected types. The ISUM record instructs *TABLES* to create water right summary tables organized in user-selected formats. A ISRT record creates a listing of water rights sorted in priority order or a listing by type of use, control point, water right type, or water right group in priority order. The ICPT record provides options for rearranging control point records in upstream-to-downstream order and developing listings of control points with user-specified information.

Type 2 routines provide an array of formats for organizing, analyzing, summarizing, and displaying *SIM* simulation results. Most of the types 5, 6, 7, and 8 options described in the *Supplemental Manual* are analogous to the type 2 features covered in the *Users Manual*. Basic concepts reflected in type 2 routines are described in the following sections of this chapter.

Table 5.7  
Outline of Program *TABLES* Features

---

*TABLES* Features Covered in Chapter 4 of the *Users Manual*

Type 1: Tables developed from *SIM* input DAT file (1REC, 1SUM, 1SRT, 1CPT).

Type 2: Tables developed from *SIM* output OUT file.

- Time series tables (input records identifiers listed in Table 5.1)
- Reliability and frequency tables (2REL, 2RET, 2FRE, 2FRQ, 2RES)
- Summary tables (2SCP, 2SWR, 2SRE, 2SGP, 2SBA)
- Water budget tables (2BUD)

Type 3: *SIM* input records developed from *SIM* output OUT file (3REG, 3NAT, 3UNA, 3DEP, 3U+D, 3EPD).

Type 4: Tables from *SIM* hydropower and reservoir release HRR file (4SWR, 4SGP) and *SIM* priority sequence flow availability ZZZ file (4ZZZ and 4ZZF).

*TABLES* Features Covered in the *Supplemental Manual*

Type 5: Conditional reliability tables developed from *SIM* or *SIMD* CRM file (5CRM, 5CR1, 5CR2, 5COR).

Type 6: Sub-monthly time step time series, reliability, and frequency tables from *SIMD* SUB file (type 6 version of time series records listed in Table 5.1, 6REL, 6FRE, 6FRQ, 6RES).

Type 7: Flood frequency analyses table developed from *SIMD* AFF file (7FFA).

Type 8: Tables of salinity simulation results from *SALT* SAL file (8SAL, 8FRE, 8FRQ, 8SUM, 8REL, 8CON).

---

Type 3 records are used to convert time sequences of naturalized flows, regulated flows, unappropriated flows, and/or stream flow depletions read from a *SIM* OUT file into the format of *IN* or *TS* records that can be incorporated into a *SIM* input DAT file. Similar more comprehensive capabilities for converting *SIM* simulation results to *SIM* input records are contained in program *HYD* as discussed in Chapter 6. These features address modeling applications in which results from a *SIM* simulation reflecting a certain water management scenario are incorporated into the input of other *SIM* simulations.

Type 4 records develop tables from *SIM* HRR and ZZZ output files which are discussed in Chapter 6 of this manual. The primary purpose of the HRR file is comparison of releases from the individual reservoirs of a multiple-reservoir system. Monthly or annual tables are created with releases from all reservoirs associated with a multiple-reservoir system water right (4SWR record) or group of system water rights (4SGP record). The *SIM* ZZZ output file and associated *TABLES* 4ZZZ and 4ZZF input records provide capabilities described in Chapter 6 for tracking the effects of each individual water right in the priority sequence on stream flows at specified control points.

## Time Series Tables and Tabulations

The time series data read from the *SIM* simulation results OUT file may be written by *TABLES* to the tables in the *TABLES* output TOU file and/or as records to a DSS file. Optionally, moving averages or moving accumulative totals of the data for a user-specified number of months may be computed and written to the TOU file and/or the DSS file. The data may also be adjusted by a multiplier factor, such as unit conversion factors, or subtracted from a given constant, such as computing reservoir drawdown as capacity minus storage content.

The original *SIM* simulation results or computed moving averages, moving totals, or otherwise adjusted time series data may be transformed by *TABLES* to the following formats.

- A text file with the filename extension TOU has each time series organized into a separate table with annual rows and monthly columns with headings illustrated by Table 5.8. Each of the variables selected from the 32 variables listed in Table 5.1 is presented as a set of separate tables for each selected water right, control point, or reservoir/hydropower project. This format is designed for report preparation and convenient viewing of simulation results.
- Each variable of interest may be tabulated as one column of a table written to the TOU file along with the tables described above. Either monthly simulation results or annual totals may be tabulated. A monthly table would be 12 times longer than the table of annual totals shown in Table 5.9. Any of the 32 variables and any water right, control point, or reservoir/hydropower project may be selected for inclusion in the up to 100 column tabulation. This format is designed for convenient transport to Microsoft Excel or other spreadsheet programs for plotting or further computations.
- A binary file with the filename extension DSS has each time series variable of interest stored as a HEC-DSS record. This format is designed to allow the data to be read by HEC-DSSVue for plotting or further computations. Figure 5.1 is a plot of monthly regulated flows created with HEC-DSSVue from a DSS file created with *TABLES*. Monthly or annual time series of any of the variables listed in Table 5.1 may be converted by *TABLES* to DSS records and plotted with HEC-DSSVue.

All *SIM* and *TABLES* input and output files except DSS files are in standard text format that can be read and viewed with Microsoft WordPad or other editors. The *TABLES* columnar format option facilitates importing the time series into Microsoft Excel or other spreadsheet programs. *TABLES* also converts the time series to records stored in a DSS file to be read by HEC-DSSVue. *SIM* simulation results can be stored directly by *SIM* as DSS or SOU files, but *TABLES* also allows the data manipulations noted above.

HEC-DSSVue can be downloaded from the Hydrologic Engineering Center website and activated directly from *WinWRAP*. The Hydrologic Engineering Center (2005) provides detailed instructions in its use. A primary motivation for connecting HEC-DSSVue to *WRAP* is its capabilities for plotting time series graphs like Figure 5.1. However, HEC-DSSVue provides an array of other graphics, data tabulation, statistics, and computational capabilities that may also be useful for organizing and analyzing *WRAP* simulation results.



Table 5.8  
 Example of a Time Series Table with Annual Rows and Monthly Columns

WATER SURFACE ELEVATION FOR RESERVOIR Whit

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1940	533.66	532.89	531.44	531.41	531.08	533.70	533.70	533.70	533.70	532.78	533.70	533.70	532.96
1941	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70	533.70
1942	533.62	533.02	532.37	533.70	533.70	533.70	530.98	530.90	532.62	533.70	533.70	533.70	532.98
1943	533.09	532.35	532.90	533.70	533.70	533.70	533.28	529.30	527.92	526.19	525.72	524.19	530.50
1944	523.15	523.91	525.86	525.12	533.70	533.61	530.55	526.37	526.05	524.17	523.16	522.49	526.51
1945	523.82	531.23	533.70	533.70	533.70	533.70	533.70	531.03	529.12	532.26	531.10	530.15	531.44
1946	530.73	533.70	533.70	533.70	533.70	533.70	530.09	529.71	533.44	533.70	533.70	533.70	532.80
1947	533.70	533.70	533.70	533.70	533.70	533.70	533.16	529.69	527.63	526.15	524.95	526.98	530.90
1948	526.81	529.62	530.42	528.98	530.20	531.39	532.17	531.28	529.74	529.37	529.11	527.83	529.74
1949	526.82	527.43	528.97	529.83	533.70	533.70	533.70	533.05	533.05	533.34	533.63	531.56	531.50
1950	531.08	533.70	533.25	533.70	533.70	533.65	533.70	533.70	533.70	533.70	533.54	533.43	533.41
1951	533.33	533.57	533.54	533.48	533.70	533.70	533.18	532.15	530.39	528.85	527.45	526.02	531.61
1952	523.94	522.20	520.98	522.11	525.27	522.10	520.98	520.01	519.23	518.42	520.98	520.98	521.43
1953	520.98	520.98	520.98	520.98	523.14	520.98	520.98	520.54	520.36	520.98	520.98	520.95	521.07
1954	520.93	520.59	520.38	520.91	520.98	522.60	521.57	520.66	520.10	520.80	520.98	520.81	520.94
1955	520.76	520.98	520.98	520.98	528.14	529.47	528.93	528.60	528.22	533.70	533.53	533.40	527.31
1956	533.36	532.75	532.66	532.96	533.70	533.26	532.38	528.44	526.28	525.08	523.43	523.66	529.83
1957	521.96	523.98	523.12	533.70	533.70	533.70	533.70	533.48	533.04	533.70	533.70	533.70	530.96
1958	533.70	533.70	533.70	533.70	533.70	533.50	533.70	533.70	533.54	532.48	531.38	530.57	533.12
1959	529.22	528.61	527.49	527.01	526.03	526.00	527.85	528.20	528.22	533.70	533.70	533.70	529.14
1960	533.70	533.70	533.70	533.70	533.70	532.95	533.70	533.61	531.96	533.70	533.70	533.70	533.49
1961	533.70	533.70	533.70	533.56	533.04	533.70	533.70	533.70	532.34	533.70	533.70	533.70	533.52
1962	533.46	532.68	531.41	531.03	529.58	533.70	533.70	533.70	533.70	533.70	533.70	533.70	532.84
1963	533.41	532.52	532.14	533.70	533.70	533.70	533.16	529.39	529.17	529.13	529.38	528.13	531.46
1964	527.11	526.37	526.53	527.42	526.80	524.02	523.08	520.98	521.76	520.98	525.40	523.98	524.54
1965	523.85	529.04	528.66	528.08	533.70	533.54	529.95	526.34	524.77	523.07	521.90	520.98	526.99
1966	520.98	520.98	520.98	527.69	533.70	533.70	530.26	527.33	533.70	533.70	533.67	532.86	529.13
1967	532.32	531.05	531.07	530.62	529.92	531.33	531.08	530.44	531.33	530.60	529.70	529.22	530.72
1968	533.70	533.70	533.70	533.70	533.70	533.70	533.70	531.38	529.89	528.66	527.82	526.65	531.69
1969	525.04	524.05	527.67	533.29	533.70	533.70	533.56	531.28	530.88	531.81	531.37	531.58	530.66
1970	531.97	533.51	533.70	533.70	533.70	533.20	529.63	529.15	528.63	528.46	527.22	525.76	530.72
1971	524.13	522.51	520.98	520.98	522.75	522.54	520.98	520.67	520.43	532.03	533.30	533.70	524.59
1972	533.70	533.70	533.70	533.27	532.97	532.88	532.41	531.79	532.69	533.01	532.20	531.31	532.80
1973	531.81	532.89	533.56	533.70	533.70	533.70	533.70	533.39	533.70	533.70	533.70	533.58	533.43
1974	533.70	533.57	533.29	532.49	531.43	530.21	529.75	528.18	529.61	531.54	533.70	533.70	531.77
1975	533.70	533.70	533.70	533.70	533.70	533.70	532.39	530.03	528.40	526.72	524.61	522.71	530.59
1976	521.61	520.98	520.98	523.24	528.36	528.51	527.88	523.80	521.67	522.09	524.10	524.51	523.98
1977	524.43	526.93	533.70	533.70	533.70	533.70	532.63	528.86	526.42	526.04	526.42	526.41	529.41
1978	524.77	523.68	522.12	522.09	522.88	520.98	520.23	519.78	519.40	519.53	520.78	521.22	521.46
1979	520.98	520.98	527.26	530.95	533.70	533.70	531.25	528.18	526.52	525.77	523.75	523.17	527.18
1980	522.20	521.14	520.98	520.98	521.67	520.98	520.47	519.78	520.01	519.64	520.04	520.41	520.69
1981	520.33	520.59	521.77	520.98	520.98	528.45	524.56	520.98	520.98	533.70	533.70	533.64	525.06
1982	533.15	533.49	533.70	533.70	533.70	533.70	533.70	533.54	533.26	533.07	531.94	530.81	533.15
1983	529.53	528.60	527.99	526.64	528.20	526.11	521.61	520.98	520.61	520.56	520.55	520.46	524.32
1984	521.03	520.98	520.98	520.53	520.19	519.91	519.17	518.61	518.07	520.98	520.98	523.02	520.37
1985	525.09	523.47	527.45	529.90	531.48	533.70	533.35	532.07	532.35	532.44	531.62	530.79	530.31
1986	529.30	529.45	528.24	527.04	528.04	533.70	530.36	527.64	530.66	533.70	533.70	533.70	530.46
1987	533.70	533.70	533.70	533.70	533.70	533.70	533.54	530.55	528.84	528.38	527.54	526.73	531.48
1988	525.60	524.36	522.77	520.98	520.97	522.56	522.25	520.98	521.29	521.02	520.82	521.10	522.06
1989	520.98	522.42	526.67	527.74	533.70	533.70	532.17	529.43	529.03	529.05	528.88	528.82	528.55
1990	528.70	528.73	533.24	533.70	533.70	533.70	530.62	530.36	530.34	530.60	529.78	528.81	531.02
1991	528.53	527.93	526.26	528.42	529.65	533.70	533.43	533.70	533.16	533.70	533.70	533.70	531.32
1992	533.70	533.70	533.70	533.70	533.70	533.70	533.70	531.75	530.44	529.03	528.25	528.51	531.99
1993	528.40	532.88	533.70	533.70	533.70	533.70	530.20	526.21	525.05	529.67	528.89	528.38	530.37
1994	527.81	527.69	527.79	526.82	533.70	533.70	531.23	530.98	531.89	533.41	533.70	533.70	531.04
1995	533.70	533.70	533.70	533.70	533.70	533.70	532.75	533.70	533.70	532.81	532.33	531.55	533.26
1996	530.59	530.87	529.56	529.63	529.36	527.94	527.50	527.14	531.69	532.51	533.70	533.70	530.35
1997	533.70	533.70	533.70	533.70	533.70	533.70	533.70	531.10	529.42	528.22	526.97	528.03	531.64
MEAN	528.49	528.80	529.18	529.71	530.78	531.05	530.05	528.62	528.41	529.09	528.94	528.65	529.32

Table 5.9  
Example of a Time Series Table with Columnar Format

	WSE Whit	REG PK	REG Whit	REG WacoL	REG WacoG	REG High	REG Belton	REG George	REG Grang	REG Camer	REG Bryan	REG Hemp
1940	533.	609001.	960729.	272764.	1592601.	2088888.	395017.	90464.	318032.	1673082.	4072310.	5233300.
1941	534.	3258658.	4088860.	699272.	5244092.	6021732.	1331568.	119541.	400520.	2898893.	9376748.	10171189.
1942	533.	1091776.	2162636.	696321.	3502712.	3980242.	1031677.	18169.	94254.	1761355.	5969242.	6136762.
1943	531.	190736.	226388.	24203.	536425.	654845.	180429.	19033.	50010.	338995.	1217041.	600518.
1944	527.	0.	94946.	370771.	1183318.	1949815.	796638.	63172.	224077.	2088508.	4954642.	6322829.
1945	531.	61891.	773248.	705926.	2255380.	2933956.	748221.	41483.	191520.	1844566.	5524224.	7162484.
1946	533.	348926.	805975.	257017.	1392210.	1935124.	480651.	37325.	160531.	1375068.	4159842.	5896686.
1947	531.	553023.	758965.	126544.	1181960.	1433612.	220417.	34533.	128228.	779966.	2485817.	3061788.
1948	530.	406386.	381596.	0.	645960.	693067.	183038.	11389.	54936.	237293.	1013219.	397094.
1949	532.	267670.	600204.	45949.	958580.	1100793.	39896.	249.	802.	300974.	1472027.	1964502.
1950	533.	314369.	565292.	0.	731368.	825645.	30539.	0.	0.	111466.	1181134.	1696867.
1951	532.	492834.	594196.	627.	736029.	748034.	6238.	223.	978.	21261.	762074.	126380.
1952	521.	0.	11527.	0.	301461.	363544.	37013.	5406.	27467.	126417.	534828.	428901.
1953	521.	311565.	291259.	108286.	649666.	917422.	67617.	9972.	57283.	534193.	1914404.	2324499.
1954	521.	578358.	565974.	4078.	649065.	659504.	0.	240.	12957.	34112.	705734.	152468.
1955	527.	745181.	652723.	0.	717706.	808218.	43469.	146.	12752.	204306.	1120174.	510484.
1956	530.	343302.	418073.	0.	665599.	693564.	65422.	739.	4630.	63273.	737057.	169016.
1957	531.	2715611.	4254029.	609612.	5447402.	6306072.	748348.	71377.	268591.	2463207.	9528487.	10685191.
1958	533.	518696.	1069313.	283077.	1657103.	2065564.	427078.	53821.	193706.	1371932.	3798908.	3860195.
1959	529.	273430.	627180.	326553.	1271860.	1616798.	306078.	52926.	202144.	1000589.	2850414.	3111920.
1960	533.	311038.	584303.	239145.	1080570.	1580928.	382114.	50367.	188995.	1461118.	3632746.	4294280.
1961	534.	591993.	1141560.	817534.	2390424.	2979373.	738507.	55451.	201449.	1958046.	5335313.	6541116.
1962	533.	694479.	994063.	31741.	1354522.	1439817.	11625.	0.	19485.	270185.	1727754.	1126383.
1963	531.	613488.	615538.	0.	763675.	785106.	189043.	216.	2494.	235751.	1007895.	382515.
1964	525.	122763.	132318.	43432.	550366.	637213.	203862.	163.	19716.	359312.	862942.	315011.
1965	527.	0.	208857.	538955.	1428944.	2146742.	637731.	68183.	225582.	2242896.	4883964.	5402762.
1966	529.	695300.	798695.	283049.	1666939.	1823906.	291691.	1828.	187516.	1061780.	3537392.	3667118.
1967	531.	439206.	444808.	0.	730825.	914203.	167957.	349.	782.	318507.	1287434.	377211.
1968	532.	287264.	1225955.	757064.	2607601.	3177232.	626998.	79461.	307200.	1989678.	5734862.	7766706.
1969	531.	668832.	1048807.	236752.	1801859.	1969023.	78857.	41141.	208235.	733593.	3063535.	3656947.
1970	531.	25701.	620229.	278053.	1277054.	1508217.	419334.	81372.	171150.	1172574.	2981807.	3005670.
1971	525.	333644.	507111.	177482.	985347.	1160851.	208661.	0.	20804.	325489.	1560941.	815262.
1972	533.	448806.	554935.	62499.	748877.	857168.	78196.	1064.	37360.	272324.	1281969.	711239.
1973	533.	83781.	769603.	266385.	1628162.	2463495.	0.	10433.	146182.	735907.	3743544.	5633755.
1974	532.	260274.	481128.	174757.	1177118.	1818234.	96502.	111768.	239928.	934101.	3156029.	4265922.
1975	531.	316221.	860809.	271856.	1628336.	2172774.	369974.	93849.	262443.	1574277.	4063340.	4678672.
1976	524.	39809.	9841.	167668.	876002.	1488695.	43976.	63295.	140827.	831278.	3006385.	3630270.
1977	529.	297033.	744426.	474512.	1807740.	2197667.	639257.	34926.	200225.	1452385.	4120546.	4514329.
1978	521.	609751.	468970.	0.	630613.	659486.	139523.	3341.	3360.	155424.	870878.	344397.
1979	527.	0.	372135.	215100.	1093170.	1762521.	0.	24250.	151045.	1085282.	3997048.	5404661.
1980	521.	426556.	388273.	41256.	738370.	956981.	127513.	27233.	104708.	466906.	1698384.	1585621.
1981	525.	685823.	856586.	83442.	1355592.	1715633.	0.	87725.	250433.	849662.	2869096.	2988590.
1982	533.	1607361.	2167872.	145748.	2394058.	2568173.	0.	35526.	131093.	306179.	2915530.	2533518.
1983	524.	191484.	163325.	55563.	560223.	695848.	17860.	40139.	115256.	404536.	1346579.	2010297.
1984	520.	46664.	56488.	36582.	282652.	468065.	25950.	2382.	2265.	183677.	794367.	1607746.
1985	530.	367031.	320034.	159843.	881109.	1231743.	1215.	22194.	158277.	643469.	2303526.	2959296.
1986	530.	452877.	498598.	303508.	1365598.	1901962.	229203.	50417.	193414.	1145286.	3595308.	4067372.
1987	531.	691856.	1381713.	175483.	1869920.	2275772.	525823.	75313.	324569.	1748907.	4556556.	5071964.
1988	522.	371189.	346594.	24601.	630163.	662609.	307705.	9034.	19695.	344352.	1074862.	319499.
1989	529.	218059.	1068293.	325789.	1885435.	2270481.	21940.	0.	9927.	123254.	2612692.	2231878.
1990	531.	1204822.	2450521.	335400.	3209152.	3518046.	424260.	0.	0.	594848.	4467988.	4138865.
1991	531.	1167444.	2327877.	712304.	3727072.	4294449.	510276.	21007.	183376.	1762694.	6872109.	8052059.
1992	532.	1556231.	2750723.	774352.	4184471.	5254312.	1477800.	198648.	546823.	3987261.	10868120.	13084108.
1993	530.	118002.	308810.	220067.	991424.	1452050.	427565.	69719.	232379.	1246096.	3379547.	4530224.
1994	531.	325227.	527942.	302651.	1297480.	1396384.	281615.	0.	0.	513484.	2152835.	3194309.
1995	533.	15956.	1044952.	753256.	2398259.	2565618.	492667.	0.	48989.	931663.	3921200.	3822911.
1996	530.	243565.	394157.	75725.	821366.	960674.	317437.	439.	16099.	444554.	1570224.	581159.
1997	532.	351445.	1745997.	966384.	3537467.	4253932.	1152960.	99832.	455040.	2977848.	8052053.	7977756.

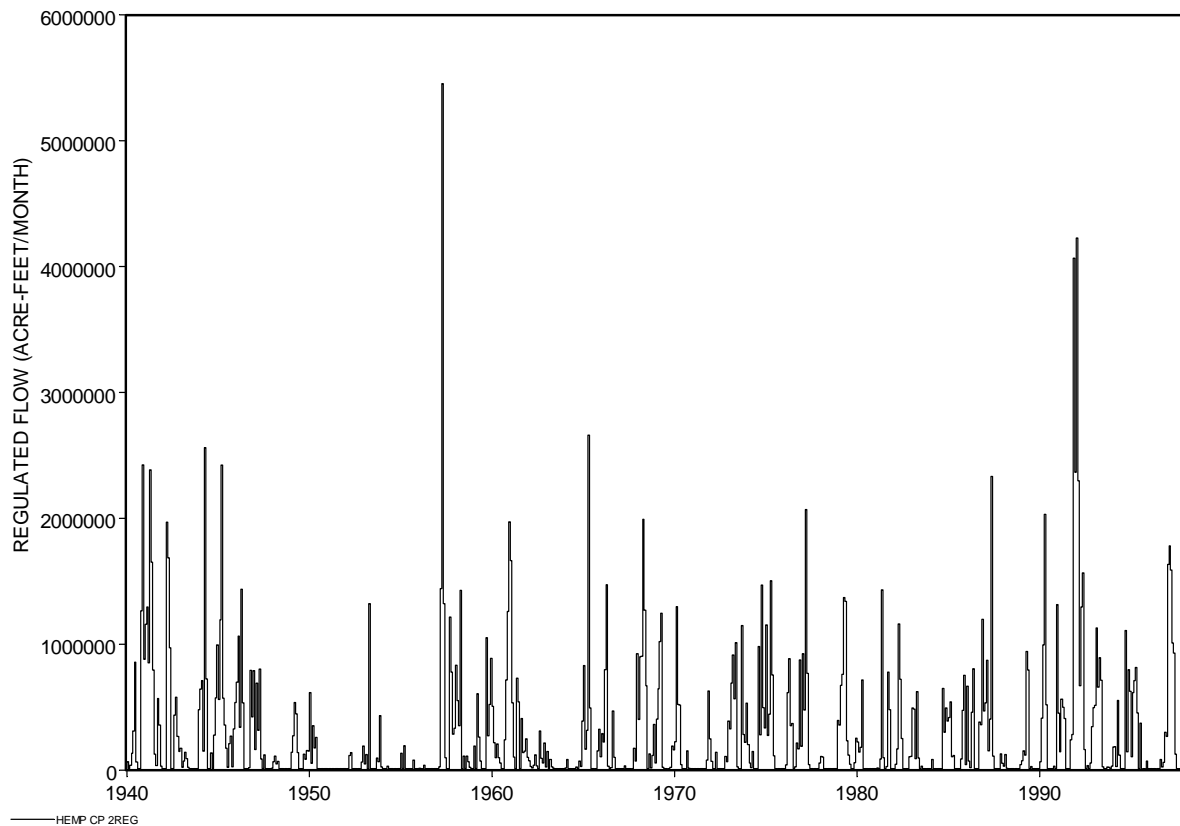


Figure 5.1 Time Series Plot Created with HEC-DSSVue

### Reliability and Frequency Tables

WRAP-SIM simulates

- development, management, allocation, regulation, and use of the water resources of a river basin or multiple-basin region in accordance with water use requirements and institutional water allocation systems utilizing constructed facilities including reservoir projects, conveyance systems, and hydroelectric power plants
- during each sequential month of a hydrologic period-of-analysis with river basin hydrology represented by sequences of monthly naturalized stream flows and net evaporation-precipitation depths.

Capabilities are assessed for meeting water use requirements under a defined scenario of water resources development and management during given sequences of naturalized flows and net reservoir evaporation-precipitation rates. The future is of concern, not the past. However, since future hydrology is unknown, historical past stream flows and reservoir evaporation-precipitation rates are typically adopted as being statistically representative of the hydrologic characteristics of a river basin that can be expected to continue into the future. The results of a *SIM* simulation are viewed from the perspectives of frequency, probability, percent-of-time, or reliability of meeting water supply, instream flow, hydropower, and/or reservoir storage requirements.

Concise measures of water availability/reliability are useful in analyzing and displaying simulation results and assessing water management capabilities. *TABLES* options described in the *Users Manual* include the following metrics for concisely summarizing *SIM* results.

- volume and period reliability tables for water supply diversion and hydroelectric energy generation targets [*TABLES* 2REL record]
- frequency tables for naturalized, regulated, and unappropriated flows, reservoir storage volumes and water surface elevations, and instream flow shortages [*TABLES* 2FRE and 2FRQ records]
- reservoir drawdown-duration and storage-reliability tables [2RES record]

The reliability and frequency tables may be developed either considering all months or alternatively for a specified individual month of the year such as July or November.

### **Water Supply and Hydropower Reliability**

Reliability tables for meeting water supply diversion and hydroelectric energy generation requirements are developed with the 2REL record. A reliability table contains both volume and period reliabilities.

#### Volume and Period Reliabilities

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

$$R_v = \frac{v}{V} (100\%) \quad (5.1)$$

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

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

$$R_p = \frac{n}{N} (100\%) \quad (5.2)$$

where  $n$  denotes the number of periods during the simulation for which the specified percentage of the demand target is met, and  $N$  is the total number of periods considered. The 2REL record develops a reliability table with periods defined alternatively in terms of both months and years. The 2REL record allows  $N$  and  $n$  to be defined on a monthly basis optionally either considering

all months or only months with non-zero demand targets. The 6REL record described in the *Supplemental Manual* allows use of *SIMD* results with a sub-monthly time step such as a day.

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

### TABLES 2REL Tables

The tables reproduced here to illustrate the format of tables produced with *TABLES* are from the example presented in the *Fundamentals Manual*. The complete dataset of *SIM* and *TABLES* input and output files is presented in the *Fundamentals Manual*. Tables 5.10 and 5.11 illustrate the format of water supply diversion and hydropower reliability tables created with a 2REL record.

Water supply diversion reliabilities may be tabulated for individual water rights, the aggregation of all rights associated with individual control points, or user-selected groups of water rights. The user selects which water rights, control points, or water rights groups to include in a diversion reliability table. Reliabilities for diversion targets for each of the individual water rights included in the example are tabulated in Table 5.10. A reliability table for aggregated diversion targets and shortages for defined groups of water rights has the same format. Likewise, diversion targets and shortages for all water rights located at each control point are summed for a control point reliability table which has the same format except the first column is a list of control points.

Table 5.11 illustrates the format of reliability tables for reservoir/hydropower projects. The table may contain any number of reservoir/hydropower projects with their individual reliabilities. However, the energy targets/shortages and corresponding reliabilities can not be aggregated by control point or other grouping.

As indicated in Table 5.1, hydroelectric energy targets and shortages are stored on both reservoir/hydropower output records and water right records. Multiple water rights with different priorities may generate energy at the same reservoir. However, only the cumulative total energy associated with the most junior right, which is computed last in the priority sequence, is written to the OUT file on reservoir/hydropower records and included in a 2REL record reliability table for reservoir/hydropower projects. The intermediate cumulative energy amounts generated by the senior rights are recorded on water right output records and may be included in a water right reliability table.

The reliabilities may be for a specified single month of the year such as August or for all 12 months. The reliabilities in Table 5.10 are for all months as indicated by no month being identified in the table headings. The reliabilities represent probabilities of supplying demands irrespective of season of the year. If August tends to be dry, reliabilities of meeting demands in August computed based on frequency counts considering only August will be lower.

Table 5.10  
Reliability Table from the Example in the *Fundamentals Manual*

RELIABILITY SUMMARY FOR SELECTED WATER RIGHTS

NAME	TARGET	MEAN	*RELIABILITY*		+++++++ PERCENTAGE OF MONTHS ++++++							----- PERCENTAGE OF YEARS -----					
	DIVERSION (AC-FT/YR)	SHORTAGE (AC-FT/YR)	PERIOD (%)	AMOUNT (%)	WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET							PERCENTAGE OF TARGET DIVERSION AMOUNT					
					100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%
WR-6	60000.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
WR-1	9800.0	128.37	98.28	98.69	98.3	98.3	98.4	98.6	98.9	98.9	100.0	87.9	89.7	89.7	93.1	100.0	100.0
WR-2	245000.0	10227.33	94.25	95.83	94.3	94.5	94.7	94.8	95.3	96.1	100.0	82.8	84.5	84.5	87.9	94.8	96.6
WR-14	11300.0	179.59	98.85	98.41	98.9	98.9	98.9	99.0	99.0	99.1	100.0	91.4	91.4	93.1	94.8	98.3	98.3
WR-20	34500.0	364.52	98.99	98.94	99.0	99.0	99.1	99.1	99.4	99.7	100.0	87.9	87.9	91.4	96.6	100.0	100.0
WR-22	49600.0	1487.60	97.84	97.00	97.8	98.1	98.4	98.6	99.0	99.0	100.0	81.0	84.5	87.9	89.7	94.8	100.0
WR-16	2679.74	2679.74	95.26	91.70	95.3	95.5	95.5	95.8	96.3	96.4	100.0	63.8	67.2	69.0	75.9	79.3	96.6
WR-17	44800.0	4720.00	94.83	89.46	94.8	94.8	94.8	95.1	95.8	96.6	100.0	60.3	62.1	62.1	67.2	77.6	93.1
WR-13	18200.0	808.66	96.12	95.56	96.1	96.1	96.1	96.3	96.7	96.8	100.0	77.6	77.6	77.6	79.3	91.4	100.0
WR-19	39000.0	1687.55	96.55	95.67	96.6	96.6	96.6	96.7	96.8	97.0	100.0	75.9	75.9	75.9	79.3	91.4	100.0
WR-21	95600.0	5169.71	95.55	94.59	95.5	95.7	95.7	95.8	96.0	96.1	100.0	69.0	70.7	70.7	72.4	91.4	100.0
WR-8	82760.0	4896.89	92.53	94.08	92.5	92.5	93.1	93.4	93.7	94.5	100.0	81.0	81.0	84.5	86.2	89.7	96.6
WR-9	97500.0	7655.33	91.09	92.15	91.1	91.4	91.4	91.4	91.8	91.8	100.0	79.3	81.0	81.0	84.5	87.9	91.4
WR-10	25610.0	4709.84	76.44	81.61	76.4	76.7	77.3	78.7	80.9	83.3	100.0	51.7	55.2	60.3	63.8	70.7	81.0
WR-11	42000.0	4052.37	86.49	90.35	86.5	86.6	87.2	87.9	90.4	92.5	100.0	63.8	67.2	70.7	81.0	86.2	91.4
WR-3	18000.0	1231.56	93.39	93.16	93.4	93.4	93.4	93.4	93.4	93.5	100.0	81.0	81.0	81.0	81.0	87.9	94.8
WR-12	92100.0	28924.62	81.47	68.59	81.5	82.2	82.3	83.3	86.2	90.9	100.0	17.2	19.0	22.4	24.1	43.1	77.6
WR-18	25400.0	2806.28	90.52	88.95	90.5	90.5	90.5	90.5	91.1	91.4	100.0	48.3	48.3	50.0	55.2	82.8	98.3
WR-7	20800.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
WR-15	88000.0	5014.48	93.82	94.30	93.8	93.8	94.1	94.3	94.5	95.0	100.0	86.2	86.2	86.2	87.9	89.7	91.4
WR-23	74500.0	21116.87	86.21	71.66	86.2	86.2	86.2	86.6	87.6	88.6	100.0	32.8	34.5	34.5	44.8	51.7	67.2
WR-24	900000.1	32627.69	95.26	96.37	95.3	95.4	95.4	95.5	96.1	97.6	100.0	82.8	84.5	86.2	89.7	93.1	98.3
WR-5	This water right has no diversion target.																
WR-25	This water right has no diversion target.																
WR-26	This water right has no diversion target.																
WR-27	This water right has no diversion target.																
WR-28	This water right has no diversion target.																
Total	2106770.0	140488.98		93.33													

Table 5.11  
Hydropower Reliability Table from the Example in the *Fundamentals Manual*

RELIABILITY SUMMARY FOR SELECTED HYDROELECTRIC POWER PROJECTS

NAME	ENERGY	MEAN	*RELIABILITY*		+++++++ PERCENTAGE OF MONTHS ++++++							----- PERCENTAGE OF YEARS -----						
	TARGET	SHORTAGE	PERIOD (%)	AMOUNT (%)	WITH ENERGY GENERATION EQUALING OR EXCEEDING PERCENTAGE OF TARGET							PERCENTAGE OF TARGET						
					100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%
Whit	36000.0	2192.75	90.66	93.91	90.7	90.7	90.8	91.7	94.4	95.5	100.0	70.7	72.4	75.9	79.3	91.4	96.6	100.0
Total	36000.0	2192.75		93.91														

A reliability summary includes tabulations of period reliabilities expressed both as the percentage of months and the percentage of years during the simulation during which diversions or energy produced equaled or exceeded specified magnitudes expressed as a percentage of the target demand. For example, the table shows the percentage of months in the simulation for which the computed diversion equals or exceeds 75% of the monthly diversion target. It also

shows the percentage of years for which the total diversions during the year equal or exceed 75% of the annual target amount. The table also shows the percentage of months for which the demand is fully 100% supplied, without any shortage.

Water right WR-1 in Table 5.10 has a mean annual diversion target of 9,800 acre-feet/year, mean annual shortage of 128.37 acre-feet/year, and a corresponding (Equation 5.1) volume reliability of 98.69 percent. Period reliabilities are based on Equation 5.2. The monthly diversion targets are fully met during 98.28 percent of the 696 months of the 1940-1997 hydrologic period of analysis. At least 90 percent of the monthly target is supplied during 98.4% of the 696 months. At least 90 percent of the annual target is supplied during 93.1% of the 58 years of the simulation.

Reliabilities for hydroelectric power generation at Whitney Reservoir (reservoir identifier Whit) are shown in Table 5.11. The monthly hydropower targets sum to a total annual target of 36,000 kilowatt-hours/year. The mean annual shortage is 2,192.5 kilowatt-hours/year, and thus the mean annual energy production from Equation 5.1 is 93.91 percent of the target. The energy target is fully met during 90.66 percent of the 696 months (Equation 5.2). Energy production equals or exceeds 75 percent of the target during 91.7 percent of 696 months and during 91.4 percent of the 58 years of the simulation.

These frequency statistics may be interpreted as follows. The WR-1 diversion shown in Table 5.10 equals or exceeds 90 percent of the monthly target an estimated 98.4 percent of the time. At least 90 percent of the annual demand is supplied an estimated 93.1 percent of the time. The estimated probability of supplying at least 90 percent of the monthly target in any randomly selected future month is 0.984. The estimated probability of supplying at least 90 percent of the annual target in any randomly selected future year is 0.931. These estimates reflect all of the premises and approximations incorporated into the modeling system and thus are necessarily approximate. For example, hydrologic variables such as river flows are highly variable, stochastic, and uncertain. The model and resulting reliabilities are typically based on the premise that historical hydrology is statistically representative of the climatic and hydrologic characteristics of the river basin to be expected in the future. Data describing the physical and institutional features of water management systems as well as river basin hydrology are also necessarily approximate. Uncertainties are inherent in modeling water management and use practices.

The reliabilities computed by *TABLES* must be interpreted in the context of the targets selected for inclusion in the *SIM* simulation results output file. *SIM* has a variety of options for specifying diversion and hydroelectric energy targets as a function of reservoir storage and stream flow. An option activated by the *SO* record allows specification of which original, intermediate, or final target developed during the target building process is written to the *SIM* output file. The default is to write the last target and shortage amount to the output file. *TABLES* reads the values written in the *SIM* output file and computes the water supply diversion or energy generated as the target less the shortage. A *2REL* record allows specification of the target to be adopted by *TABLES* for volume reliability computations.

The firm yield associated with a particular water supply diversion or hydroelectric power production target is defined as the maximum annual demand target that can be met with a reliability of 100.0 percent. Firm yields may be determined by iteratively adjusting a target

amount and rerunning *SIM* until a value meeting the definition of firm yield at a prescribed level of precision is found. As discussed in Chapter 6, The *FY* record activates a *SIM* option that automates this procedure. The reliabilities computed by the *FY* record yield-reliability routine in *SIM* are based on Equations 5.1 and 5.2 just like the *TABLES 2REL* record reliability routine. The difference is that the *FY* record routine computes reliabilities for one single diversion right with the target incremented multiple times. Any number of diversion rights may be included in a *TABLES 2REL* record reliability table, but all diversion targets are fixed at set values.

A procedure for applying ArcGIS to display *SIM* simulation results is noted in Chapter 6 of this manual. A map of the river/reservoir system has color coded symbols indicating ranges in which reliabilities and frequencies fall at control locations.

### **Flow and Storage Frequency Analyses**

Exceedance frequency is an expression of the percentage-of-time or equivalently the likelihood or probability that a variable of interest will equal or exceed a certain amount. Exceedance frequency tables may be created with *TABLES 2FRE* and *2FRQ* records for:

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

The frequencies may be based on considering all months or alternatively be developed for a specified month of the year such as May or August.

Applications of *TABLES 2FRE* frequency analysis capabilities may deal directly with the time series data read from the *SIM* simulation results OUT file. Optionally, the frequency analysis may be applied to moving averages or moving accumulative totals of the data computed for a user-specified number of months. The data may be adjusted by a multiplier factor, which may be a unit conversion factor or serve other purposes. The data may be added or subtracted from a constant entered on the *2FRE* record. For example, the time series data for a frequency analysis of reservoir draw-downs is developed by subtracting water surface elevations from the inputted top of conservation pool elevation or storage volume may be subtracted from capacity. Likewise, deviations of regulated flows from a specified flow amount may be analyzed.

Table 5.12 illustrates the default standard format of a *2FRE* frequency table. The *2FRE* table includes the mean and standard deviation, minimum and maximum, and the flow or storage amounts that are equaled or exceeded specified percentages of the time. The *2FRE* record also includes an option to write the frequencies and corresponding amounts as columns rather than rows. The alternative columnar format is convenient for transporting the tabulations to Microsoft Excel for plotting and also contains several more frequencies.

The *2FRQ* record also develops a frequency table for the same types of flow or storage variables, but in a different format illustrated by Table 5.13. The model-user enters specified flow or storage values of interest on the *2FRQ* record. *TABLES* counts the number of months for



which that specified amount was equaled or exceeded and applies Equation 5.3 to assign a frequency. The relative frequency counting method based on Equation 5.3 is the only option available for developing the 2FRQ frequency table. This method is also the default option for the 2FRE table. However, as discussed later, the 2FRE record also provides options for applying the normal (Gaussian) or log-normal probability distributions.

Table 5.12  
2FRE Frequency Table from the Example in the *Fundamentals Manual*

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	STANDARD MEAN 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	43379.9 119616.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	2643.	50903.	107827.	1782155.
Whit	73686.7 183326.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.	10233.	38502.	78247.	189804.	2970632.
WacoL	21636.4 51914.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	17515.	71069.	526063.
WacoG	128848.3 237675.	0.0	0.0	379.8	4409.6	11904.6	32638.3	45087.	61528.	75692.	115784.	303863.	3361572.	
High	158249.7 269466.	0.0	0.0	1118.7	5733.5	16778.2	39742.9	58647.	73201.	96101.	137398.	385570.	3581146.	
Belton	27018.6 65029.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	1194.	19413.	92619.	524452.
George	3004.7 7642.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	283.	10841.	65552.
Grang	11394.4 23276.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	1598.	10439.	41255.	200100.
Camer	82002.9 150359.	42.0	295.9	295.9	295.9	305.8	4587.1	13109.	24392.	45981.	90476.	214237.	1392558.	
Bryan	270525.3 430255.	0.0	7575.1	14093.2	32484.5	48061.0	68692.0	98980.	113463.	130459.	277893.	676897.	4521903.	
Hemp	297707.6 538387.	9205.5	9205.5	9863.0	9863.0	9863.0	10191.8	15647.	54660.	125291.	392267.	888598.	5455438.	

Table 5.13  
2FRQ Frequency Table from the Example in the *Fundamentals Manual*

WATER SURFACE ELEVATION-FREQUENCY FOR RESERVOIR Whit FOR MONTH 8

ELEVATION FREQ(%)	ELEVATION FREQ(%)	ELEVATION FREQ(%)	ELEVATION FREQ(%)	ELEVATION FREQ(%)	ELEVATION FREQ(%)	ELEVATION FREQ(%)							
518.0	100.00	520.0	94.83	524.0	79.31	528.0	68.97	530.0	48.28	532.0	25.86	533.7	13.79

Relative Frequency

Exceedance frequencies may be determined from the results of a *SIM* simulation based on counting the relative frequency in which various quantities are equaled or exceeded. Relative frequency is expressed by Eq. 5.3 where n is the number of months during the simulation that a particular flow or storage amount is equaled or exceeded, and N is the total number of months considered.

$$\text{Exceedance Frequency} = \frac{n}{N} (100\%) \quad (5.3)$$

The *Fundamentals Manual* example is based on a 58-year 1940–1997 hydrologic period-of-analysis. N is 696 months for Table 5.12 with all months considered in the frequency analysis. N is 58 months in Table 5.13 which was developed for the particular month of August.

In developing the 2FRE table for the predefined exceedance frequencies shown in the heading of Table 5.12, *TABLES* sorts and searches the flow or storage data to find a value that is equaled or exceeded during the specified percentage of the months of the simulation. If a single monthly flow value does not precisely match that frequency, linear interpolation is applied to the two flow values that bracket the specified frequency. In developing the 2FRQ table for user-specified flow or storage amounts, *TABLES* simply counts the number of months for which a specified amount (518 ft, 520 ft, 524 ft, 528 ft, 530 ft in Table 5.13) was equaled or exceeded.

Table 5.12 is frequency table for regulated stream flows based on considering all months. At the Bryan control point, the minimum and maximum regulated flow during the 696-month 1940-1997 simulation period is 0.0 and 4,521,903 acre-feet/month, respectively. The mean and standard deviation of regulated flows at the Bryan control point are 270,525 and 430,255 acre-feet/month, respectively. A flow of 14,093 ac-ft/month is equaled or exceeded during 98 percent of the 696 months of the hydrologic period-of-analysis. The regulated flow volume is at least 98,980 acre-feet during 60 percent of the 696 months. Thus, flows equal or exceed 98,980 ac-ft/month an estimated 60 percent of the time. The estimated probability that the flow volume at the Bryan control point will be at least 98,980 acre-feet in any randomly selected month is 0.60 for the water management and use scenario and modeling premises incorporated in the *WRAP-SIM* simulation model and input dataset.

#### Normal and Log-Normal Probability Distributions

Alternatively, the *TABLES 2FRE* record provides options to apply the normal (Eq. 5.4) or log-normal (Eq. 5.5) probability distribution to the series of flow and storage amounts generated by *SIM* or adjustments thereto.

$$X = \bar{X} + z S \quad (5.4)$$

$$\log X = \overline{\log X} + z S_{\log X} \quad (5.5)$$

The frequency factor ( $z$ ) is derived from a normal probability table.  $\bar{X}$  and  $S$  denote the mean and standard deviation of the data read from the *SIM* output file.  $\overline{\log X}$  and  $S_{\log X}$  are the mean and standard deviation of the logarithms of these data. The log-normal distribution consists of the normal distribution applied to the logarithms of  $X$ , with Eq. 5.4 expressed as Eq. 5.5 with  $z$  still derived from the normal probability distribution.

The random variable  $X$  in Equations 5.4 and 5.5 is the naturalized flows, regulated flows, unappropriated flows, instream flow shortages, reservoir storage volumes, or reservoir water surface elevations from the *SIM* simulation results or variations thereof reflecting adjustments made within *TABLES*. The mean  $\bar{X}$  and standard deviation  $S$ , computed from these data using Equations 5.6 and 5.7, are the parameters used to model frequency relationship as the log-normal or normal probability distributions.

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i \quad (5.6)$$

$$S = \left[ \frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2 \right]^{0.5} \quad (5.7)$$

For the log-normal distribution, the mean  $\overline{\log X}$  and standard deviation  $S_{\log X}$  of the logarithms of the data from the *SIM* output file are computed and entered into Equation 5.5.

In the routines activated by the 2FRE record that apply the probability distribution options, exceedance probabilities are assigned to the random variable  $X$  by fitting the normal or log-normal distribution in the standard manner outlined in statistics books. The frequency factor  $z$  for specified exceedance frequencies tabulated in Table 5.14 are derived from the normal probability table and are built into *TABLES*. All of the frequencies listed in Table 5.14 are included if the results of the 2FRE frequency computations are tabulated in columnar format. With the standard row format illustrated earlier by Table 5.12, several of the frequencies are omitted to reduce the width of the table.

Table 5.14  
Frequency Factors for the Normal Probability Distribution

Exceedance Frequency	Factor $z$ in Eqs. 5.4 & 5.5	Exceedance Frequency	Factor $z$ in Eqs. 5.4 & 5.5
99.9%	-3.09023	0.1%	3.09023
99.5%	-2.57583	0.5%	2.57583
99%	-2.32637	1%	2.32635
98%	-2.05377	2%	2.05375
95%	-1.64487	5%	1.64485
90%	-1.28156	10%	1.28156
80%	-0.84162	20%	0.84162
75%	-0.67450	25%	0.67450
70%	-0.52440	30%	0.52440
60%	-0.25335	40%	0.25335
50%	0.00000		

#### Choice of Alternative Frequency Method

The 2FRE record choice between applying the concept of relative frequency directly using Eq. 5.3 versus adopting the normal (Eq. 5.4) or log-normal (Eq. 5.5) probability distributions depends upon the particular variable and application. When in doubt, the default relative frequency counting option based on Eq. 5.3 should probably be adopted. The normal or log-normal probability distribution functions offer potential improvements in the accuracy of the frequency estimates. One of the two alternative distributions should be considered for adoption if statistical goodness-of-fit tests made outside of WRAP demonstrates a reasonably close fit to the data. However, if the data do not closely fit either probability distribution function, Eq. 5.3 is the optimal choice of computation method.

A conventional frequency plot on normal probability paper of the data or logarithms of the data versus frequency calculated based on Eq. 5.3 provides a subjective measure of the closeness-of-fit of the probability distributions. If the normal or log-normal distribution accurately models the probability characteristics of the flow or storage variable of interest, the resulting frequency relationship will be close to the frequencies computed with Eq. 5.3 for a large sample size N, with the fit improving with increasing N.

The probability distributions perhaps may be more useful for frequency analyses for a particular month where the sample size N is only 1/12 of the size when considering all months. Conditional reliability modeling (CRM) is described in the *Supplemental Manual*. The random variable is defined differently in CRM versus conventional simulations. The log-normal or normal distribution options may be particularly relevant for CRM applications.

The log-normal distribution allows the random variable to range from zero upward with no defined upper limit, which is consistent with stream flows. The normal distribution is symmetric about the mean with no lower and upper limits. The log-normal distribution will typically be a reasonably valid model for monthly naturalized stream flow volumes. Regulated and unappropriated flows are affected by water management practices that may invalidate application of the log-normal distribution. Storage capacity sets an upper limit on storage volumes that likely prevents proper fitting of either the normal or log-normal distributions, except perhaps for reservoirs that are never or seldom completely full or completely empty during the simulation. The distributions may be more appropriately applied to storage draw-downs rather than storage.

### **Reservoir Contents, Drawdown Duration, and Storage Reliability**

Reservoir storage frequency tables may be developed using 2FRE or 2FRQ records for either water rights, control points, or reservoirs as discussed in the preceding section. The 2RES record provides an alternative format for storage frequency analyses based on storage volumes from reservoir/ hydropower output records. The 2RES record results in three tables for selected reservoirs:

1. storage contents as a percentage of storage capacity
2. drawdown-duration relationships
3. storage-reliability relationships

The first table is a tabulation of end-of-month storage content expressed as a percentage of the storage capacity of a user-specified zone. The storage content as a percentage is

$$\text{storage content as percentage of capacity} = \frac{S - C_2}{C_1 - C_2} (100\%) \quad (5.8)$$

where  $C_1$  and  $C_2$  are the user-specified total storage capacity below the water surface elevations defining the top and bottom of the storage zone or pool being considered. Often  $C_1$  will be the total conservation storage capacity and  $C_2$  will be entered as zero.  $C_1$  may be the total conservation capacity, and  $C_2$  the inactive storage capacity. Other zones may be analyzed as well. The storage percentage is negative for a storage content less than  $C_2$  and greater than 100% for a storage content greater than  $C_1$ . The table format is illustrated by Table 5.15 which shows only the first 14 months

of the 696 months included in the table. This type of table is designed for comparing storage in the different reservoirs of a system.

The 2RES drawdown-duration table illustrated by Table 5.16 shows the number of months of the simulation for which the end-of-month drawdown exceeds given percentages of the storage capacity of the specified storage zone. Drawdowns are expressed as a percentage of storage capacity as follows. The terms in Eq. 5.9 are defined the same as in Eq. 5.8.

$$\text{drawdown as percentage of capacity} = 100\% - \frac{S - C_2}{C_1 - C_2}(100\%) \quad (5.9)$$

Table 5.15  
Beginning of Table of Reservoir Storage Content as a Percentage of Capacity

END-OF-PERIOD RESERVOIR STORAGE AS A PERCENTAGE OF CAPACITY

Percentage = 100% \* (S - C2) / (C1 - C2) where  
S = end-of-month storage  
C1,C2 = user defined top and bottom of storage zone

YEAR	MONTH	MEAN	PK	Whit	WacoL	Belton	George	Grang
1940	1	95.50	87.31	99.44	97.41	96.35	95.54	96.93
1940	2	93.22	86.27	88.84	95.41	94.41	95.05	99.36
1940	3	77.35	82.16	76.30	91.77	91.32	91.02	31.53
1940	4	81.85	80.95	76.02	100.00	94.82	97.11	42.20
1940	5	85.36	96.14	73.19	94.87	92.20	100.00	55.76
1940	6	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1940	7	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1940	8	96.15	100.00	100.00	92.41	94.09	94.45	95.95
1940	9	88.58	87.04	100.00	87.22	89.41	87.47	80.33
1940	10	68.26	82.59	87.94	83.51	78.79	-0.65	77.41
1940	11	96.95	93.67	100.00	100.00	100.00	88.00	100.00
1940	12	99.93	99.58	100.00	100.00	100.00	100.00	100.00
1941	1	99.75	98.50	100.00	100.00	100.00	100.00	100.00
1941	2	100.00	100.00	100.00	100.00	100.00	100.00	100.00

*TABLES* counts and tabulates the number of months during the simulation for which the draw-down defined by Equation 5.9 equals or exceeds 0%, 2%, 5%, 10%, 25%, 50%, 75%, 90%, and 100% of the storage capacity defined by Equation 5.8. For example in Table 5.16, for Possum Kingdom Reservoir (identifier PK), the drawdown is at least 10 percent of the specified storage capacity during 476 months of the 696-month hydrologic period-of-analysis.

Alternatively, the storage-reliability table illustrated by Table 5.17 shows the frequency that specified storage levels are equaled or exceeded. Possum Kingdom Reservoir (PK) is full at 100 percent capacity during 17.7 percent of the months of the 696 month simulation. Storage in PK equals or exceeds 95 percent of capacity defined by Equation 5.8 during 25.7 percent of the 696 months. PK is at least 75 percent full 48.0 percent of the time for the scenario modeled.

Table 5.16  
Reservoir Storage Drawdown Duration Table

RESERVOIR STORAGE DRAWDOWN DURATION

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	NUMBER OF PERIODS WITH DRAWDOWNS EQUALING OR EXCEEDING PERCENT OF ZONE STORAGE CAPACITY								
				0%	2%	5%	10%	25%	50%	75%	90%	100%
PK	375510.09	0.	570240.	696.	549.	517.	476.	362.	197.	91.	70.	48.
Whit	533629.19	379000.	627100.	696.	477.	454.	428.	360.	246.	156.	116.	88.
WacoL	170133.27	580.	192100.	696.	405.	360.	276.	111.	22.	0.	0.	0.
Belton	273345.34	0.	457600.	696.	534.	516.	483.	394.	269.	161.	101.	68.
George	18583.93	240.	37100.	696.	545.	521.	488.	410.	332.	284.	234.	181.
Grang	36947.18	220.	65500.	696.	473.	454.	431.	385.	308.	223.	165.	119.

Table 5.17  
Reservoir Storage Reliability Table

RESERVOIR STORAGE RELIABILITY

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING PERCENTAGE OF STORAGE CAPACITY								
				100%	98%	95%	90%	75%	50%	25%	10%	>0%
PK	375510.09	0.	570240.	17.5	21.1	25.7	31.6	48.0	71.7	86.9	89.9	100.0
Whit	533629.19	379000.	627100.	30.0	31.5	34.8	38.5	48.3	64.7	77.6	83.3	94.0
WacoL	170133.27	580.	192100.	36.9	41.8	48.3	60.3	84.1	96.8	100.0	100.0	100.0
Belton	273345.34	0.	457600.	21.0	23.3	25.9	30.6	43.4	61.4	76.9	85.5	100.0
George	18583.93	240.	37100.	20.0	21.7	25.3	29.9	41.1	52.3	59.2	66.4	74.0
Grang	36947.18	220.	65500.	30.0	32.0	34.8	38.1	44.7	55.7	68.0	76.3	82.9

**Summary Tables**

Overview summaries of simulation results created by 2SBA, 2SCP, 2SWR, 2SGP, and 2SRE record routines consist of either a monthly or annual tabulation of selected data items contained on the *SIM* control point, water right, or reservoir/hydropower output records. A monthly table has an additional column for the month and 12 times as many rows as an annual table.

A 2SBA record results in a basin(s) summary table reflecting the entire dataset. The naturalized, regulated, and unappropriated stream flows in the 2SBA table are the maximum of the values found at any of the control points. The other tabulated data are the summation of values for all of the control points.

A 2SCP record instructs *TABLES* to create a summary table for each of any number of control points. Table 5.18 is an annual summary table for a selected control point from the example. The corresponding monthly summary table would be 12 times as long. Naturalized, unappropriated, and regulated flows are defined for control points. The stream flow depletions, diversions, and diversion shortages are the summations for all water rights at the control point. End-of-period storage and net evaporation-precipitation are totals for all reservoirs, though typically no more than one reservoir will be assigned to a control point.

Table 5.18  
Summary Table for a Control Point

ANNUAL SUMMARY TABLE FOR CONTROL POINT WacoL

YEAR	NATURALIZED SIREAMFLOW (AC-FT)	REGULATED SIREAMFLOW (AC-FT)	UNAPPROPRIATED SIREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	SIREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1940	371606.0	272764.2	272764.2	0.0	98841.8	192100.0	18041.8	80800.0	0.0
1941	786143.0	699272.0	699272.0	0.0	86871.0	180426.7	17744.3	80800.0	0.0
1942	807665.0	696321.4	695669.2	0.0	111343.6	192100.0	18870.3	80800.0	0.0
1943	86189.0	24202.5	24202.5	0.0	61986.5	144659.4	28627.1	80800.0	0.0
1944	484119.0	370771.3	370771.3	0.0	113347.7	158000.1	19207.0	80800.0	0.0
1945	839250.0	705926.0	705926.0	0.0	133324.0	192100.0	18424.1	80800.0	0.0
1946	319845.0	257017.3	257017.3	0.0	62827.7	151214.8	22912.9	80800.0	0.0
1947	222143.0	126544.1	126544.1	0.0	95598.9	137579.7	28434.0	80800.0	0.0
1948	92400.0	0.0	0.0	0.0	92400.0	118431.7	30748.0	80800.0	0.0
1949	197405.0	45949.4	45949.4	0.0	151455.6	164508.5	24578.8	80800.0	0.0
1950	104406.0	0.0	0.0	0.0	104406.0	159026.2	29088.3	80800.0	0.0
1951	56302.0	626.6	0.0	0.0	5675.4	103430.9	30470.6	80800.0	0.0
1952	146643.0	0.0	0.0	0.0	146643.0	142814.6	26459.3	80800.0	0.0
1953	208278.0	108286.1	108286.1	0.0	99991.9	139803.4	22203.0	80800.0	0.0
1954	77612.0	4078.1	0.0	0.0	73533.9	103856.9	28680.5	80800.0	0.0
1955	85964.0	0.0	0.0	0.0	85964.0	95316.8	13704.0	80800.0	0.0
1956	84638.0	0.0	0.0	0.0	84638.0	74209.5	24945.3	80800.0	0.0
1957	810381.0	609612.1	609612.1	0.0	200768.9	192100.0	2078.4	80800.0	0.0
1958	358209.0	283077.1	278152.5	0.0	75131.9	174397.5	12034.4	80800.0	0.0
1959	430167.0	326553.0	326553.0	0.0	103614.0	192100.0	5111.5	80800.0	0.0
1960	332707.0	239145.2	239145.2	0.0	93561.7	192100.0	12761.7	80800.0	0.0
1961	905330.0	817534.1	812503.4	0.0	87796.0	192100.0	6996.0	80800.0	0.0
1962	114884.0	31741.3	31741.3	0.0	83142.7	173308.7	21134.0	80800.0	0.0
1963	31304.0	0.0	0.0	0.0	31304.0	99749.9	24062.9	80800.0	0.0
1964	231187.0	43432.2	35082.5	0.0	187754.8	192100.0	14604.6	80800.0	0.0
1965	628020.0	538955.2	538955.2	0.0	89064.8	192100.0	8264.8	80800.0	0.0
1966	365306.0	283048.8	283048.8	0.0	82257.1	178549.1	15008.1	80800.0	0.0
1967	93176.0	0.0	0.0	0.0	93176.0	170760.3	20164.8	80800.0	0.0
1968	866935.0	757064.1	757064.1	0.0	109870.9	192100.0	7731.2	80800.0	0.0
1969	335551.0	236752.0	236752.0	0.0	98799.0	192100.0	17999.0	80800.0	0.0
1970	360312.0	278053.3	273366.2	0.0	82258.7	173951.8	19606.9	80800.0	0.0
1971	294933.0	177481.8	95357.3	0.0	117451.2	192100.0	18503.0	80800.0	0.0
1972	145642.0	62499.1	58575.7	0.0	83143.0	173896.8	20546.1	80800.0	0.0
1973	373173.0	266385.3	266385.3	0.0	106787.7	190252.1	9632.4	80800.0	0.0
1974	271745.0	174756.8	174756.8	0.0	96988.2	192100.0	14340.3	80800.0	0.0
1975	336531.0	271856.5	271856.5	0.0	64674.5	161005.1	14969.4	80800.0	0.0
1976	287178.0	167667.9	167667.9	0.0	119510.1	192100.0	7615.2	80800.0	0.0
1977	516605.0	474512.0	474512.0	0.0	42093.0	132225.3	21167.7	80800.0	0.0
1978	27175.0	0.0	0.0	0.0	27175.0	61607.5	16992.8	80800.0	0.0
1979	407641.0	215099.9	215099.9	0.0	192541.0	166448.1	6900.4	80800.0	0.0
1980	109917.0	41256.1	41256.1	0.0	68661.0	133651.5	20657.6	80800.0	0.0
1981	209736.0	83442.4	83442.4	0.0	126293.6	170854.7	8290.3	80800.0	0.0
1982	250406.0	145747.6	145747.6	0.0	104658.4	177820.8	16892.3	80800.0	0.0
1983	120294.0	55562.7	55562.7	0.0	64731.3	146630.1	15122.0	80800.0	0.0
1984	179582.0	36582.4	36563.9	0.0	142999.6	192100.0	16729.7	80800.0	0.0
1985	252679.0	159843.3	156591.1	0.0	92835.7	192100.0	12035.7	80800.0	0.0
1986	392465.0	303507.5	298446.2	0.0	88957.5	192100.0	8157.5	80800.0	0.0
1987	254806.0	175482.8	175482.8	0.0	79323.2	178125.2	12498.0	80800.0	0.0
1988	103290.0	24601.1	4077.6	0.0	78689.0	155049.5	20964.6	80800.0	0.0
1989	426796.0	325789.2	323798.8	0.0	101006.8	160614.6	14641.7	80800.0	0.0
1990	421306.0	335400.2	335400.2	0.0	85905.8	155482.0	10238.4	80800.0	0.0
1991	836758.0	712304.5	679372.9	0.0	124453.5	192100.0	7035.5	80800.0	0.0
1992	861217.0	774352.3	774352.3	0.0	86864.7	192100.0	6064.7	80800.0	0.0
1993	291384.0	220066.9	220066.9	0.0	71317.1	164686.0	17931.1	80800.0	0.0
1994	423579.0	302650.5	302650.5	0.0	120928.5	192100.0	12714.5	80800.0	0.0
1995	834946.0	753255.6	723807.9	0.0	81690.4	183596.2	9394.2	80800.0	0.0
1996	179875.0	75724.9	56180.5	0.0	104150.1	192100.0	14846.3	80800.0	0.0
1997	1052548.0	966384.4	966384.4	0.0	86163.5	192100.0	5363.6	80800.0	0.0
MEAN	356832.5	259636.9	255720.3	0.0	97195.6	165209.3	16395.6	80800.0	0.0

Likewise, 2SWR and 2SRE records create summary tables for specified water rights or reservoirs. A 2SGP record results in a summation of certain data on the *SIM* water right output records of multiple rights with the same group identifier in fields 12 or 13 of the *WR* input records. The water right group summary table has the summation of the stream flow depletions, diversions, and diversion shortages associated with all water rights with the specified group identifier.

### **Water Budget Tables**

A 2BUD record develops two types of tables.

1. A monthly water budget tabulation may be created for a selected control point or all control points for each month of the simulation. This is a very lengthy tabulation.
2. A river basin water budget is a very concise summary table aggregating data computed for all individual control points and all months into period-of-analysis basin totals.

Monthly computations are performed for all control points in developing the 2BUD total river basin water budget table. The 2SBA, 2SCP, 2SWR, 2SGP, and 2SRE summary tables described above tabulate *SIM* simulation results with only minor additional computations. The 2BUD routine uses *SIM* input and output data in relatively extensive computations which are required to develop all components of a complete water budget. The water budgets are tabulations of the individual components of inflows to and outflows from the control point or river basin along with changes in reservoir storage. The following water budget equation is confirmed.

$$\text{sum of all inflows} - \text{sum of all outflows} = \text{change in storage}$$

The water budget routines were initially developed with the program *SALT*. The detailed accounting of inflow and outflow components is required for tracking salt loads and concentrations through the system. The water budget routines within *SALT* are an integral part of the simulation. The same basic computations are consolidated into the *TABLES* 2BUD record routine. The two types of tables created by the 2BUD record have general utility in analyzing simulation results.

The *TABLES* 2BUD water budget computations are based on reading the simulation results from a *SIM* output OUT file containing output records for all control points included in the *SIM* DAT file. Additional information is also read from the *SIM* DAT file. Two different types of water budget tables may be developed, river basin and individual control point. Computations are performed for all control points in the process of developing the river basin water budget table. Results associated with individual control points are recorded in the individual control point water budget table. The computations step sequentially through time and, for each month, are performed by control point in upstream-to-downstream order.

Table 5.19 shows the first 24 months of a water budget table for the Waco Lake control point. The entire tabulation is 696 months long. Table 5.20 is the complete water budget summary table for the entire river basin for the entire hydrologic period-of-analysis.

The variables in the control point water budget tabulation and the river basin summary water budget table are defined in Tables 5.21 and 5.22, respectively. The variable names used in the Fortran code are adopted in Tables 5.21 and 5.22 and the following discussion.



Table 5.19  
Beginning of Control Point Water Budget Tabulation

YEAR	M	CPID	NAI(CP)	CI(CP)	CL(CP)	INAI	REG	REI(CP)	CINF	FLC	FL	REG(CP)	DIV	FOH	EMAP(CP)	BSIO(CP)	SIO(CP)	XSIO	XSUM
1940	1	WaccL	1166.	0.	0.	1166.	0.	0.	0.	0.	0.	0.	5252.	0.	869.	192100.	187145.	-4955.	-4955.
1940	2	WaccL	1315.	0.	0.	1315.	0.	0.	0.	0.	0.	0.	5090.	0.	56.	187145.	183313.	-3831.	-3831.
1940	3	WaccL	1182.	0.	0.	1182.	0.	0.	0.	0.	0.	0.	5494.	0.	2661.	183313.	176339.	-6974.	-6974.
1940	4	WaccL	36755.	0.	0.	36755.	0.	0.	0.	0.	0.	15680.	5818.	0.	-503.	176339.	192100.	15761.	15761.
1940	5	WaccL	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	6868.	0.	2959.	192100.	182273.	-9827.	-9827.
1940	6	WaccL	61991.	0.	0.	61991.	0.	0.	0.	0.	0.	45625.	7514.	0.	-975.	182273.	192100.	9827.	9827.
1940	7	WaccL	41936.	0.	0.	41936.	0.	0.	0.	0.	0.	28529.	9534.	0.	3872.	192100.	192100.	0.	0.
1940	8	WaccL	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9211.	0.	5321.	192100.	177568.	-14532.	-14532.
1940	9	WaccL	2999.	0.	0.	2999.	0.	0.	0.	0.	0.	0.	7676.	0.	5260.	177568.	167631.	-9937.	-9937.
1940	10	WaccL	2477.	0.	0.	2477.	0.	0.	0.	0.	0.	0.	7030.	0.	2563.	167631.	160515.	-7116.	-7116.
1940	11	WaccL	93211.	0.	0.	93211.	0.	0.	0.	0.	0.	59268.	5737.	0.	-3378.	160515.	192100.	31585.	31585.
1940	12	WaccL	128574.	0.	0.	128574.	0.	0.	0.	0.	0.	123662.	5575.	0.	-663.	192100.	192100.	0.	0.
1941	1	WaccL	45901.	0.	0.	45901.	0.	0.	0.	0.	0.	39855.	5252.	0.	794.	192100.	192100.	0.	0.
1941	2	WaccL	129987.	0.	0.	129987.	0.	0.	0.	0.	0.	125764.	5090.	0.	-868.	192100.	192100.	0.	0.
1941	3	WaccL	94948.	0.	0.	94948.	0.	0.	0.	0.	0.	89462.	5494.	0.	-8.	192100.	192100.	0.	0.
1941	4	WaccL	133705.	0.	0.	133705.	0.	0.	0.	0.	0.	128068.	5818.	0.	-180.	192100.	192100.	0.	0.
1941	5	WaccL	174943.	0.	0.	174943.	0.	0.	0.	0.	0.	167566.	6868.	0.	409.	192100.	192100.	0.	0.
1941	6	WaccL	76423.	0.	0.	76423.	0.	0.	0.	0.	0.	68016.	7514.	0.	892.	192100.	192100.	0.	0.
1941	7	WaccL	61285.	0.	0.	61285.	0.	0.	0.	0.	0.	47837.	9534.	0.	3913.	192100.	192100.	0.	0.
1941	8	WaccL	46901.	0.	0.	46901.	0.	0.	0.	0.	0.	32704.	9211.	0.	4986.	192100.	192100.	0.	0.
1941	9	WaccL	5494.	0.	0.	5494.	0.	0.	0.	0.	0.	0.	7676.	0.	4802.	192100.	185116.	-6984.	-6984.
1941	10	WaccL	1926.	0.	0.	1926.	0.	0.	0.	0.	0.	0.	7030.	0.	-72.	185116.	180084.	-5032.	-5032.
1941	11	WaccL	7916.	0.	0.	7916.	0.	0.	0.	0.	0.	0.	5737.	0.	1955.	180084.	180308.	224.	224.
1941	12	WaccL	6814.	0.	0.	6814.	0.	0.	0.	0.	0.	0.	5575.	0.	1120.	180308.	180427.	119.	119.

Table 5.20  
River Basin Water Budget for Example in Fundamentals Manual

River Basin Volume Budget Summary  
1940-1997

	Total	Mean Annual
Naturalized flows	310818880.	5358946.0
Return flows	23167034.	399431.6
CI record constant inflows	0.	0.0
Channel loss credits	6617931.	114102.3
Channel losses	2631164.	45364.9
Regulated flows at outlet	207204368.	3572489.0
Diversions	114044272.	1966280.5
Other flows at control points	10817725.	186512.5
Net evaporation	6154304.	106108.7
-----		
Inflows - Outflows	-247988.	-4275.7
-----		
Beginning reservoir storage	1949640.	33614.5
Ending reservoir storage	1701194.	29330.9
-----		
Change in storage	-248446.	-4283.6
-----		
Water balance difference	458.	7.9
Negative inflows to control points	71220.	1227.9
Negative incremental natural flows	4060064.	70001.1
Naturalized flows at outlet	310818816.	5358945.0

Table 5.21  
Monthly Volumes in the Control Point Water Budget Table

Variable	Description of Variable
1 YEAR	year
2 M	month (1, 2, 3, ... , 12)
3 CPID(cp,1)	control point identifier
<i>Monthly Volumes Used in Intermediate Computations</i>	
4 NAT(cp)	naturalized flow from <i>SIM</i> output file
5 CLC(cp)	downstream channel loss credits from <i>SIM</i> output file
6 CL(cp)	downstream channel losses from <i>SIM</i> output file
<i>Monthly Control Point Inflows in Volume Budget</i>	
7 FNAT	computed incremental naturalized flows
8 FREG	computed regulated flows entering control point
9 RET(cp)	return flows from <i>SIM</i> output file
10 CINF(cp,m)	<i>CI</i> record inflows from <i>SIM</i> input file
11 FCLC	computed upstream channel loss credits
12 FCL	computed upstream channel losses
13 FIN	total inflows to control point = FNAT+FREQ+RET(cp)+CINF(cp,m)+FCLC-FCL
<i>Monthly Control Point Outflows in Volume Budget</i>	
14 REG(cp)	regulated flows leaving control pt from <i>SIM</i> output file
15 DIV	diversion = target – shortage from <i>SIM</i> output file
16 FOTH	other releases for hydropower and instream flow = FIN – [REG(cp)+DIV+EVAP(cp)+STO(cp)–BSTO(cp)]
17 EVAP(cp)	net reservoir evaporation from <i>SIM</i> output file
<i>Reservoir Storage at Beginning and End of Month</i>	
18 BSTO(cp)	beginning-of-month storage
19 STO(cp)	end-of-month storage from <i>SIM</i> output file
<i>Water Budget</i>	
XSTO = XSUM	
20 XSTO	storage change = (19) – (18)
21 XSUM	inflows – outflows = (13) – (14) – (15) – (16) – (17)



represent river flows leaving the system. The other variables representing inflow and outflow or change in storage are also summed for all control points. The summation of all of the outflows and inflows for each month during the period-of-analysis equals the change in reservoir storage, which is the total storage at the end of the simulation less the total storage at the beginning. The variables included in the basin water budget table as listed above are related as follows.

$$\text{change in storage volume} = \Sigma \text{ inflow volume} - \Sigma \text{ outflow volume} \quad (5.12)$$

$$\begin{aligned} \Sigma \text{ inflow volume} - \Sigma \text{ outflow volume} &= \Sigma \text{FNAT} + \Sigma \text{RET}(\text{cp}) + \Sigma \text{CINF}(\text{cp},\text{m}) \\ &+ \Sigma \text{FCLC} - \Sigma \text{FCL} - \Sigma \text{REG}(\text{cp}) - \Sigma \text{DIV}(\text{cp}) - \Sigma \text{FOTH} - \Sigma \text{EVAP}(\text{cp}) \end{aligned} \quad (5.13)$$

$$\text{change in storage volume} = \Sigma \text{STO}(\text{cp}) - \Sigma \text{BPSTO}(\text{cp}) \quad (5.14)$$

The volume difference in the basin budget table represents losses or gains due to computer accuracy in adding numerous numbers and thus should be very close to zero.

$$\begin{aligned} \text{volume balance difference} &= \\ [\Sigma \text{ inflow volume} - \Sigma \text{ outflow volume}] &- [\Sigma \text{STO}(\text{cp}) - \Sigma \text{BPSTO}(\text{cp})] \end{aligned} \quad (5.15)$$

The physical or computational meaning of negative inflow volumes varies with different situations. The water budget table includes the entry *negative inflows to control point*. Total inflow volumes (FIN) are determined each month for each control point. Negative values for FIN are recorded as the variable FINNEG. The summation of FINNEG for all control points and all months are included in the river basin volume budget table. Options for dealing with negative control point total inflows are selected by 2BUD record field 7.

Incremental naturalized flows (FNAT) are negative if the flows at upstream control points exceed the flow at the control point in question. The summation of negative incremental volumes is included in the basin budget table for general information. The negative incremental naturalized flows generated by the *TABLES* 2BUD routine may be different than the negative incremental flow adjustments in *SIM*. Whereas *SIM* looks at all control points located optionally either downstream or upstream in computing negative incremental naturalized flow adjustments, the *TABLES* 2BUD routine considers only the upstream control point(s) located immediately adjacent to the control point being considered.

With the default blank 2BUD field 9, the last variable listed in the river basin water budget table is naturalized flows at the one or more outlets. Outlets are defined by *SIM CP* records. The total naturalized flows NAT(cp) at outlets should be the same as the sum of the incremental flows  $\Sigma \text{FNAT}$ , which is the first entry in the table.

#### Other Reservoir Releases or Other Flows

The other flow volume (FOTH) in Eq. 5.13 and Tables 5.21 and 5.22 is computed as follows.

$$\text{FIN2} = \text{flow in} = \text{flow out} + \text{storage change} \quad (5.16)$$

$$\text{FIN2} = \text{REG}(\text{cp}) + \text{DIV} + \text{EVAP}(\text{cp}) + \text{STO}(\text{cp}) - \text{BSTO}(\text{cp}) \quad (5.17)$$

$$\text{FOTH} = \text{FIN2} - \text{FIN} \quad (5.18)$$

The other flow volume FOTH is by definition the additional flow component required to make the volume budget at a control point perfectly balance.

The FOTH term models releases made specifically for hydroelectric power generation or releases from storage for meeting instream flow requirements. Passing of reservoir inflows for downstream instream flow requirements and water supply releases that incidentally generate hydropower are not included in this category of other releases. The return flows in the *SIM* output file control point records include reservoir releases to meet hydropower and instream flow requirements. Return flows incorporating these other reservoir releases are included the regulated flows and control point inflows. To maintain the volume balance, hydropower and instream flow releases must also be included in the computations in the same way as diversions as quantities in the control point outflows. *SIM* negative incremental naturalized flows and options for dealing with them (*JD* record field 8) may also prevent the control point volume budget from balancing without the FOTH term.

#### Control Point Sequencing for the 2BUD Record Water Budget

*SIM* is executed with output records for all control points written to the OUT file. Water right and reservoir output records are not needed. Within each month of the 2BUD computational algorithm, the water budget computations are performed by control point in upstream-to-downstream sequence. A control point is considered only after 2BUD computations are completed for all control point located upstream. Regulated flows from upstream control points adjusted for channel losses are a component of the inflows to the control point in question.

A 1CPT record may be placed before the 2BUD record to create an ICP(I) array stored in computer memory that defines the upstream-to-downstream ordering of control points. The default 1CPT record field 3 option 1 is selected. If the control points are already in upstream-to-downstream order in the *SIM* DAT file, the 1CPT record is not needed. Alternatively, the 1CPT record may be used to permanently rearrange the sequencing of *CP* records in a *SIM* DAT file.

A control point other than the default basin outlet may be entered in 2BUD record field 2. The river basin water budget is valid for a control point specified in field 9 only if all control points listed prior to that control point in the sequencing are located upstream, which may not necessarily be the case if the control point sequencing is performed for the entire system above the basin outlet(s). An individual control point budget for any specified control point is always fine even if the sequencing is performed considering all control points above the basin outlet(s).

## CHAPTER 6 AUXILIARY SPECIAL-PURPOSE MODELING FEATURES

The preceding Chapter 5 discusses *SIM* simulation results recorded in the OUT file and organized and analyzed with *TABLES*. The present Chapter 6 covers *SIM* simulation results stored in other supplemental output files and associated modeling and analyses techniques. Use of *SIM* output in developing *SIM* hydrology input datasets with *HYD* is also discussed. This chapter begins with an overview of *SIM* output files followed by a brief discussion of auxiliary software. The chapter then covers the following features of programs *SIM*, *TABLES*, and *HYD*.

- Yield-reliability table in *SIM* YRO file activated by firm yield *FY* record.
- Priority sequence stream flow availability table in *SIM* ZZZ file activated by *ZZ* record and associated time series and frequency tables created with *TABLES* 4ZZZ and 4ZZF records.
- End-of-simulation reservoir storage volumes recorded by *SIM* in BES file for use as beginning-of-simulation storage volumes as controlled by *JO* record field 5.
- Water right and control point data from *SIM* input DAT file tabulated with *TABLES* 1SRT, 1SUM, and 1CPT records and reservoir storage data in *SIM* output BRS file.
- Application of *HYD* for incorporating *SIM* OUT file simulation results in the development of *SIM* hydrology input data for purposes such as extending the hydrologic period-of-analysis or creating simplified *SIM* input datasets.

### SIM Output Files

The various types of *SIM* output files are referenced by their filename extensions which are tabulated in the first column of Table 6.1. The conditional reliability modeling CRM file is covered in Chapter 2 of the *Supplemental Manual*. The other *SIM* input and output files are explained in Chapter 2 of the *Users Manual*. *SIM* output files are listed in Table 6.1 and briefly described in the following paragraphs. Subsequent sections of this chapter discuss the simulation results provided in YRO, ZZZ, and BES files. The last section of this chapter addresses capabilities provided in *HYD* for using simulation results from the *SIM* OUT file in developing *SIM* hydrology input datasets.

The OUT, ZZZ, HRR, and CRM files are text files containing *SIM* simulation results that can be read, reorganized, and analyzed using program *TABLES*. The OUT file can optionally be created in an unformatted binary format read only by *TABLES*. The DSS file is in a binary format read only with HEC-DSSVue or other DSS accessible software. The text files can be examined using essentially any editor such as Microsoft WordPad. The simulation results recorded in the ZZZ file are designed to be conveniently read directly with any editor as well as reorganized and analyzed using *TABLES*. The MSS, SOU, and YRO files are designed to be read with any editor but are not read by *TABLES*. The BES file is designed to be both written by *SIM* and read by *SIM*.

The OUT, SOU, and DSS files provide the same simulation results in different formats. The CRM file is the conditional reliability version of the OUT file. Program *SIM* can not create both an OUT and CRM file in the same execution. With the OUT/CRM file exception, any or all of the other files can be generated in the same execution of *SIM*.

Table 6.1  
SIM Output Files

Filename Extension	File Activation	Contents of File	Main Reference in Addition to Users Manual
MSS	automatic	trace, error, and warning messages	Reference Manual Chapter 7
OUT	default	main simulation results read by <i>TABLES</i>	Reference Manual Chapter 5
SOU	<i>OF</i> record	main simulation results table	Reference Manual Chapter 5
DSS	<i>OF</i> record	main simulation results read by <i>HEC-DSSVue</i>	Reference Manual Chapter 5
YRO	<i>FY</i> record	yield-reliability table including firm yield	Reference Manual Chapter 6
ZZZ	<i>ZZ</i> record	priority sequence flow availability table	Reference Manual Chapter 6
BES	<i>JO</i> record	beginning and ending storage	Reference Manual Chapter 6
BRS	<i>JO</i> record	beginning reservoir storage	Reference Manual Chapter 6
HRR	<i>JO</i> record	hydropower and reservoir system releases	Reference Manual Chapter 6
CRM	<i>CR</i> record	results for conditional reliability modeling	Supplemental Man Chapter 2

### Message (MSS) File

A message file is always automatically created by *SIM* and each of the other WRAP programs. The *SIM* message file has the filename extension MSS. Message files provide trace messages tracking the progress of model execution, error and warning messages, and various other miscellaneous information. *SIM* provides options described in Chapter 7 allowing the user to select various types of information to be included in the MSS file.

### Main Simulation Results Output (OUT) File

Program *TABLES* reads the main *SIM* simulation results output file, which has the filename extension OUT, and develops an array of user-specified tables and tabulations. A model-user may occasionally read an OUT file directly to track problems or better understand the program. However, the OUT file is designed to efficiently store voluminous data in the order in which it is computed. *TABLES* converts the *SIM* output data to readily useable information. The preceding Chapter 5 focuses on the simulation results recorded in the *SIM* OUT file and its further organization and analysis with *TABLES*. Reading and manipulating *SIM* simulation results from the OUT file with program *HYD* in conjunction with developing *SIM* hydrology input datasets are discussed in the last section of Chapter 6.

### Alternative Main Simulation Results Output (SOU and DSS) Files

The OUT, SOU, and DSS files contain the same simulation results described in Chapter 5 but differ in the format in which the data are stored. The alternative *SIM* files are activated with the optional output files *OF* input record. The OUT and SOU files are text files that can be read by any editor. The OUT file is designed to be read by *TABLES*. The SOU file presents the simulation results in a columnar format which is convenient for viewing directly with any editor such as WordPad or transporting to a spreadsheet program such as Excel. *TABLES* can not read SOU or DSS files. The DSS file is designed to be read by *HEC-DSSVue* for plotting and/or other purposes.

### Yield versus Reliability Output (YRO) File

As discussed later in this chapter, the firm yield *FY* record activates a routine to develop a yield-reliability table for a diversion, which is written to the YRO file (filename extension YRO). The firm yield is the last entry in the table. *SIM* creates this yield-reliability table directly as the simulation is iteratively repeated multiple times. *TABLES* is not involved in any way with the YRO file table. However, *TABLES* creates other reliability tables for fixed targets from the results of a single simulation that are discussed in the preceding Chapter 5.

### Priority Sequence Stream Flow Availability (ZZZ) File

Simulation results stored in the *ZZZ* file activated by the *ZZ* record are also discussed later in this chapter. Regulated flows, available flows, and upstream reservoir releases at specified control points are tabulated in a *ZZZ* file after each individual water right is simulated in the priority loop. The *SIM* output *ZZZ* file table may be read directly with any editor. The *TABLES* *ZZZZ* and *ZZZF* records activate *TABLES* routines for reading a *ZZZ* file and organizing the simulation results in optional time series formats or developing frequency tables.

### Beginning-Ending Storage (BES) File

End-of-simulation reservoir storage contents may be saved for subsequent use as beginning-of-simulation reservoir storage. Beginning-ending storage (BES) options are described later in this chapter. A BES file may be both created and read by *SIM*. Program *TABLES* does not deal in any way with BES files.

### Beginning Reservoir Storage (BRS) File

The optional BRS file is a table listing all reservoirs with the following data: reservoir identifier, control point location, storage capacity, and beginning-of-simulation storage content. Program *SALT* and a *TABLES* conditional reliability modeling routine, both described in the *Supplemental Manual*, contain options to read beginning-of-simulation storage from a BRS file. The BRS file may also be useful for general information.

### Hydropower and Reservoir Release (HRR) File

The HRR file is used primarily for comparing releases from individual reservoirs of a multiple-reservoir system operated for the same water right. Simulation results in the OUT file (or SOU or DSS files) include data related to reservoirs and hydropower. However, multiple-reservoir system secondary reservoir releases, not found in the OUT file, are recorded in the optional hydropower and multiple-reservoir system release HRR file. Hydroelectric power generation is included in the HRR as well as OUT files. Tables created by *TABLES* as specified by *4SWR* and *4SGP* input records organize these data into a more convenient-to-read tabular format.

The HRR file lists releases from primary and secondary reservoirs for each month of the simulation for each water right selected for output. The release from a primary reservoir is simply the diversion supplied by the water right, which is also recorded in the OUT file. For multiple-



reservoir systems, the HRR file also provides a tabulation of the releases from each of the individual secondary reservoirs associated with a water right. Unlike the HRR file, the OUT file records only the aggregated total release from all of the secondary reservoirs. The HRR file also contains the hydroelectric energy target and amount of energy generated, which are also found in the OUT file.

### Conditional Reliability Modeling (CRM) File

Conditional reliability modeling (CRM) is covered in Chapter 2 of the *Supplemental Manual*. The CRM file activated by a CR record is described in the *Supplemental Manual*. The CRM file is the conditional reliability modeling version of the OUT file. *SIM* creates either an OUT file or CRM file, but not both. The same simulation result variables are contained in either the OUT or CRM file. However, the CRM file reflects the subdivision of the hydrologic period-of-analysis into multiple sequences associated with conditional reliability modeling.

## Auxiliary Software

As discussed initially in Chapter 1 and noted throughout this manual, use of other readily available software along with the WRAP programs serve various purposes. Other non-WRAP programs are used along with *TABLES* to organize and display *WRAP* simulation results.

### Microsoft Programs

Microsoft WordPad and NotePad are used to create WRAP input files and to read and edit input and output files. Tables created with *TABLES* are transported into Microsoft Word documents when preparing reports. Excel is used to plot simulation results and perform various computational manipulations. Both *SIM* and *TABLES* create output files in optional columnar formats for convenient transport to spreadsheet programs such as Microsoft Excel. These Microsoft programs can be accessed directly from the *WinWRAP* interface.

### Hydrologic Engineering Center HEC-DSS and HEC-DSSVue

The HEC-DSS (Data Storage System) was developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE) for use with its own generalized hydrologic, hydraulic, and water management simulation models. The HEC-DSS is used with other non-HEC modeling systems as well. Multiple simulation models share the same graphics and data management software as well as a set of basic statistical and arithmetic routines. HEC-DSS database management and graphics capabilities are designed particularly for sequential time series data such as *WRAP* simulation results and hydrology input data. The HEC-DSS Visual Utility Engine (HEC-DSSVue) is a graphical user interface program for viewing, editing, and manipulating data in DSS files. The public domain HEC-DSSVue software and documentation may be downloaded from the Hydrologic Engineering Center website. <http://www.hec.usace.army.mil/>

The WRAP Fortran programs are linked during compilation to DSS routines from a static library file provided by the Hydrologic Engineering Center that allows access to DSS files. The WRAP executable programs include options for writing the *SIM*, *SIMD*, or *SALT* simulation results as HEC-DSS files and reading and writing hydrology data. DSS files store data in a binary format

that is accessible only by HEC-DSSVue and programs such as the HEC simulation models and WRAP programs that incorporate DSS routines from the HEC-DSS library in the computer code. HEC-DSSVue can be accessed directly from the *WinWRAP* interface. The WRAP programs store the following types of data in DSS files: (1) hydrology input data consisting of stream flows and net evaporation rates and (2) simulation results including essentially all of the time series variables.

Naturalized stream flows and net evaporation-precipitation depths may be both read from and written to DSS files by either *WRAP-SIM/SIMD* or *WRAP-HYD*. Reading of hydrology data by *SIM* from a DSS file rather than the default FLO and EVA files is controlled by *JO* record field 2. Creation of a hydrology DSS file with *SIM* is activated by *OF* record field 6. Program *HYD JC* record parameters control reading and writing hydrology data by *HYD* in a DSS file.

The *SIM*, *SIMD*, and *SALT* simulation programs have options for storing simulation results as DSS files. The post-simulation program *TABLES* also includes options for writing the time series variables from the simulation results as DSS records and may also perform various arithmetic operations prior to writing the resulting adjusted simulation results as DSS records.

*SIM* output files *OF* input record field 4 activates the option of storing *SIM* simulation results in a DSS file. As discussed in Chapter 5, all of the *SIM* simulation results that can be stored in an OUT or SOU file can also be stored by *SIM* in a DSS file. The *TABLES* time series records include options for writing *SIM* OUT file data or other data computed based on the *SIM* output data to a DSS file. *TABLES* can also store *SIM* results read from a *ZZZ* file as a DSS file.

The purpose for storing WRAP simulation results as DSS files is to allow application of HEC-DSSVue primarily to develop time series graphs. HEC-DSSVue provides convenient capabilities for plotting *SIM*, *SIMD*, and *SALT* simulation results or hydrology input data. In addition to graphics, HEC-DSSVue also provides an array of data management and computation options. HEC-DSSVue statistical analyses and mathematical operations can be applied to the WRAP time series data. HEC-DSSVue is documented in detail by a users manual (Hydrologic Engineering Center 2005) which is available along with the software from the HEC website.

### *WRAP Display Tool for ArcGIS ArcMap*

Geographic information system (GIS) software is useful in dealing with spatial aspects of compiling WRAP input data and displaying simulation results. The ArcGIS software system marketed by the Environmental Systems Research Institute (<http://www.esri.com>) is a particularly popular GIS. Use of ArcGIS to develop WRAP input datasets is noted in Chapters 1 and 3.

An ArcGIS tool for displaying *WRAP-SIM* simulation results originally developed by Olmos (2004) was later improved by the Center for Research in Water Resources (2007) at the University of Texas for the TCEQ. The *WRAP Display Tool* is applied as an ArcMap toolbar. Flow and storage frequencies, water supply reliabilities, and other percentage-based indices derived from *SIM* simulation results are displayed by range as color coded symbols on a map. Time series graphs of *SIM* output data can also be plotted. The tool includes features for customizing applications along with its standard *SIM* output file manipulation and display capabilities. The *WRAP Display Tool* is available from the TCEQ as an executable setup file along with a users manual (CRWR 2007). It is designed for use with ArcGIS version 9.2.

## Yield Versus Reliability Relationships Including Firm Yield

The annual water supply diversion target or hydroelectric energy generation target is entered in the *SIM* water right *WR* record field 3 as the input variable *AMT*. Model applications may require computing volume and period reliabilities (defined by Equations 5.1 and 5.2 in Chapter 5) for a range of different values for *AMT*. The firm yield, defined as the maximum value of *AMT* that has a computed reliability of 100.0 percent, also may be of interest. The reliabilities associated with various annual yields, represented by the variable *AMT*, that includes the firm yield (100% reliability), may be developed simply by running *SIM* multiple times, manually changing the *AMT* entry in *WR* record field 3 for each run. An option activated by the *FY* record automates this procedure. In a single *SIM* execution, multiple simulations are repeated with the annual target amount being systematically changed. The resulting yield-reliability table is written as a *SIM* output file with the filename extension YRO.

The *SIM* routine to develop a yield versus reliability relationship is controlled with the firm yield *FY* record. The firm yield is the last entry in the resulting YRO file yield-reliability table, assuming a non-zero firm yield is possible. In some situations, any non-zero diversion target results in a reliability of less than 100 percent. The diversion or hydropower yield may be associated with a single water right or a set of any number of rights. If associated with multiple water rights, two options are available for allocating the annual yield amount between rights.

1. With the first option (MFY=1 on *FY* record), the yield is allocated between rights in proportion to target amounts entered in field 3 of the water right *WR* records. Thus, the total yield is multiplied by fractions set by the model-user to determine the proportion of the total yield assigned to each water right as illustrated by the following example.
2. The second option (MFY=2 on *FY* record) is based on the priorities from field 7 of the *WR* records. The yield is assigned to the most senior priority right up to the target amount specified in field 3 of its *WR* record. Any yield remaining is assigned to the next most senior priority right up to its target amount, and so forth. Upon reaching the most junior right, the remaining portion of the yield, if any, is assigned to the most junior right regardless of its *WR* record target amount.

The yield-reliability table reproduced as Table 6.2 is provided to illustrate the automated yield-reliability/firm yield option. This YRO file table is created with the following entries on a *FY* record:

```
FYIN(1) = 0.92
FYIN(2) = 200,000 acre-feet/year
FYIN(3) = 10,000 acre-feet/year
FYIN(4) = 1,000 acre-feet/year
FYIN(5) = 100 acre-feet/year
Either FYWRID = Jones Reservoir and/or FYGROUP = yield
MFY = 1
```

The yield-reliability table shown as Table 6.2 begins with a list of the water rights for which the target amounts are adjusted. *FYWRID* and *FYGROUP* from *FY* record fields 7 and 8

connect with the water right identifiers in *WR* record field 11 and group identifiers in *WR* record fields 12 and 13. The water right identifier and two group identifiers are listed for each right on the top of the yield-reliability table. Using option 1 outlined above, the annual target is divided between the rights by the percentages shown, which are computed based on directly proportioning the targets from their *WR* records. Thus, the first right in the example, which represents a municipal diversion from Jones Reservoir, accounts for 38.78% of the annual target shown in the table.

Table 6.2  
Example *SIM* Yield-Reliability Output File

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

38.782 percent: Jones Reservoir municipa yield  
 52.148 percent: Jones Reservoir industri yield  
 9.070 percent: Jones Reservoir irrigati yield

If more than one right, the target amount is distributed using the percentages shown above. The total number of periods is 696. The period reliability is the percentage of the periods for which at least 92.0 percent (FY record field 2; default=100%) of the target is supplied. The table below ends with the maximum target that results in a mean annual shortage of less than 0.05 units.

Iteration	Level	Annual Target	Mean Shortage	Mean Actual	Volume Reliability (%)	Periods Without Shortage	Period Reliability (%)
1	0	200000.0	16025.7	183974.3	91.99	630	90.52
2	1	190000.0	13327.9	176672.1	92.99	639	91.81
3	1	180000.0	10741.8	169258.2	94.03	646	92.82
4	1	170000.0	8321.3	161678.7	95.11	656	94.25
5	1	160000.0	6077.6	153922.4	96.20	664	95.40
6	1	150000.0	4533.4	145466.6	96.98	672	96.55
7	1	140000.0	3274.3	136725.7	97.66	677	97.27
8	1	130000.0	1828.7	128171.3	98.59	683	98.13
9	1	120000.0	432.1	119567.9	99.64	692	99.43
10	1	110000.0	0.00	110000.0	100.00	696	100.00
11	2	119000.0	284.9	118715.1	99.76	694	99.71
12	2	118000.0	162.5	117837.5	99.86	695	99.86
13	2	117000.0	40.5	116959.5	99.97	695	99.86
14	2	116000.0	0.00	116000.0	100.00	696	100.00
15	3	116900.0	25.6	116874.4	99.98	695	99.86
16	3	116800.0	10.7	116789.3	99.99	696	100.00
17	3	116700.0	0.00	116700.0	100.00	696	100.00
18	4	116790.0	9.24	116780.8	99.99	696	100.00
19	4	116780.0	7.76	116772.2	99.99	696	100.00
20	4	116770.0	6.27	116763.7	99.99	696	100.00
21	4	116760.0	4.78	116755.2	100.00	696	100.00
22	4	116750.0	3.29	116746.7	100.00	696	100.00
23	4	116740.0	1.80	116738.2	100.00	696	100.00
24	4	116730.0	0.32	116729.7	100.00	696	100.00
25	4	116720.0	0.00	116720.0	100.00	696	100.00

Each line in the YRO file table represents the results of a *SIM* simulation. The annual target amount *AMT* is the only input variable that changes between simulations. No other features of *WRAP-SIM* are affected. All other features remain in effect.

*FYIN(1)* entered in *FY* record field 2 is the fraction of the monthly target that must be met in order for the routine to not declare that month a failure in the computation of period reliability. *FYIN(1)* might be set at 0.92 for an analysis based on the premise that a 8% reduction in water use through demand management measures is acceptable during dry periods. The *FYIN(1)* default is 1.0, meaning the entire target must be met in order to not declare a failure in meeting the target that month. *FYIN(1)* affects only the period reliability (last two columns of table). It is not used in the volume reliability computations (columns 3, 4, 5). The firm yield criterion for stopping the iterative routine is based on reaching a total shortage of essentially zero, defined as less than 0.05 unit of the units being used (for example 0.05 acre-feet/year). If *FYIN(1)* is non-zero, the 100% period reliability yield may be larger than the 100% volume reliability yield. Both are shown in the yield-reliability table. In the example with *FYIN(5)*=0.92, the volume reliability firm yield is 116,720 ac-ft/yr and the period reliability firm yield is 116,800 ac-ft/yr.

The iterative simulations are organized as follows.

1. The total annual target amount *AMT* equals *FYIN(2)* (=200,000 ac-ft/yr) from the *FY* record for the first simulation. With *MFY* option 1, *AMT* for the initial and all subsequent iterations is distributed to multiple water rights in proportion to *WR* record field 3 *AMT*s, with resulting percentages listed at the top of the table, to determine the individual *AMT* for each of the rights. The following steps are identical regardless of which of the two *MFY* options is activated in *FY* field 9 for distributing the target amount between water rights.
2. The total annual target amount *AMT* is decreased by *FYIN(3)* for each subsequent level 1 iteration until either no shortages occur or the target is finally decreased to zero or less.
3. If both *FYIN(4)* and *FYIN(5)* are zero, the computations stop. If *FYIN(4)* is not zero, the computations proceed to level 2. In the example, since *FYIN(4)* of 1,000 ac-ft has been entered on the *FY* record, the computations proceed to level 2.
4. For level 2, the initial target amount *AMT* is set equal to the next-to-last target amount from the level 1 iterations (120,000 ac-ft). *AMT* is decreased by *FYIN(4)* (1,000 ac-ft) for each level 2 iteration until either no shortages occur or the target *AMT* reaches zero.
5. If *FYIN(5)* is zero, the computations stop without proceeding to levels 3 and 4. Otherwise, level 3 iterations are performed using *FYIN(5)* as the incremental decrease in *AMT*. For the example, *FYIN(5)* is 100 ac-ft.
6. If *FYIN(5)* is not zero, upon completion of the level 3 iterations, an extra level 4 set of iterations is performed with the incremental decrease set at 10 percent of *FYIN(5)*.

The *FY* record computations are performed for only one annual diversion or hydropower amount. A single annual target amount is adjusted during the iterative routine. However, this amount may be shared by any number of water rights (*WR* records). The water right identifier in

*FY* record field 7 is matched with the identifiers entered in water right *WR* record field 11. The water right group identifier in *FY* record field 8 is matched with the identifiers entered in water right *WR* record fields 12 and 13. The annual amount is divided between multiple rights based on the choice of two optional method specified by *MFY* in *FY* record field 9. For those rights designated by *FYWRID* and *FYGROUP* on the *WR* record, this is the only use made of the amounts entered in field 3 of their *WR* records. If only one right is designated by the *FY* record, an amount entered in field 3 of its *WR* record is not used for anything in the computations.

The example in the *Fundamentals Manual* further illustrates the methodology. The *Fundamentals Manual* is organized focusing on an example with complete dataset provided, which includes application of the firm yield *FY* record yield-reliability analysis feature of *SIM*.

### **Stream Flow Availability in the Water Rights Priority Sequence**

A *SIM* feature controlled by the *ZZ* record and associated *TABLES* routines controlled by the *4ZZZ* and *4ZZF* records are designed to facilitate assessments of the effects of other water rights located throughout the river basin on the amount of stream flow that is available to water users at particular locations of concern. For each control point specified with a *SIM ZZ* record, regulated flows, available flows, and upstream reservoir releases are tabulated in a *ZZZ* file after each individual water right is simulated in the priority loop. These monthly flows are recorded at the beginning of the water rights loop and after each individual water right is simulated in the priority sequence. *TABLES* reads the *ZZZ* file and organizes the flow information.

All *SIM* output *OUT* file variables are defined in Chapter 5 and listed in Table 5.1. An identifying label is listed in the second column of Table 5.1. Three of these previously defined variables (regulated flows, available stream flows, and upstream reservoir releases), labeled *2REG*, *2ASF*, and *2URR* in Table 5.1, are included in the *ZZZ* file. Intermediate available stream flows (*2ASF* in Table 5.1) in the water rights priority sequence become unappropriated flows (*2UNA*) after the most junior water right is simulated. The reservoir releases (*2URR*) included in the *ZZZ* table are a component of regulated flows (*2REG*) and include only releases from reservoirs located at or upstream of a control point that are made to meet water right diversion, storage, or instream flow requirements at a control point located further downstream.

The *ZZZ* file table may be read directly with any editor. The *TABLES 4ZZZ* and *4ZZF* records activate *TABLES* options for reading a *ZZZ* file and organizing the simulation results in optional time series formats or developing frequency tables. The *4ZZZ* record builds time series tables in optional formats or *DSS* files, and the *4ZZF* record creates frequency analysis tables similar to the *2FRE* record frequency tables discussed in Chapter 5.

During each month of the *SIM* simulation, flows at designated control points are tabulated in the *ZZZ* file at the beginning of the water rights priority loop and after each water right is simulated in the priority sequence. By default, all water rights from the most senior to most junior are included in the tabulation. However, an optional parameter entered on the *ZZ* record sets a minimum flow change required for a water right to be included in the table. Monthly flow volumes are tabulated after a water right is simulated only if the change in either the regulated flow, available flow, or upstream release equals or exceeds the specified limit at

one or more of the control points being considered. Another option allows the tabulation to stop after reaching a specified water right in the priority sequence. The larger Texas WAM System datasets contain hundreds of water rights. These ZZ record options allow the length of the ZZZ file table to be greatly reduced. TABLES deals with variations in water right listings between months by assigning flows to missing rights by repeating flows for the preceding right listed.

Instructions for applying the SIM ZZ record and TABLES 4ZZZ and 4ZZF records are provided in Chapters 3 and 4 of the Users Manual. Incorporation of these features in the example presented in the Fundamentals Manual results in the following Tables 6.3, 6.4, and 6.5. The ZZZ file partially reproduced as Table 6.3 was created by inserting the following ZZ record in the DAT file for the example presented in the Fundamentals Manual.

```
ZZ      2      0.01                George  Grang
```

All other SIM input and output remain unchanged. The time series and frequency tables reproduced as Tables 6.4 and 6.5 were developed with the data from the ZZZ file with TABLES using the 4ZZZ and 4ZZF records shown on the next page.

Table 6.3  
Beginning of Example ZZZ File Created with ZZ record

REGULATED AND AVAILABLE STREAMFLOWS COMPUTED IN WATER RIGHTS  
PRIORITY SEQUENCE AT CONTROL POINTS SPECIFIED BY ZZ RECORD

First year and number of years: 1940 58  
Number of water rights and control points: 30 2

Control Point				George			Grang			
Year	M	Water Right	M	WR	Reservoir Releases	Regulated Flow	Available Flow	Reservoir Releases	Regulated Flow	Available Flow
1940	1	*** Beginning **	1	0		156.0	156.0		502.0	502.0
1940	1	WR-10	1	16	0.0	0.0	0.0	0.0	1147.1	1147.1
1940	1	WR-11	1	17	0.0	0.0	0.0	0.0	0.0	0.0
1940	2	*** Beginning **	2	0		1320.0	1320.0		4249.0	4249.0
1940	2	WR-10	2	16	0.0	0.0	0.0	0.0	3714.8	3714.8
1940	2	WR-11	2	17	0.0	0.0	0.0	0.0	0.0	0.0
1940	3	*** Beginning **	3	0		464.0	464.0		1493.0	1493.0
1940	3	WR-10	3	16	0.0	0.0	0.0	0.0	1844.8	1844.8
1940	3	WR-11	3	17	0.0	0.0	0.0	0.0	0.0	0.0
1940	3	WR-15	3	22	0.0	0.0	0.0	2141.7	2141.7	0.0
1940	3	WR-24	3	24	0.0	0.0	0.0	42661.4	42661.4	0.0
1940	4	*** Beginning **	4	0		4019.0	4019.0		12931.0	12931.0
1940	4	WR-10	4	16	0.0	0.0	0.0	0.0	9793.2	9793.2
1940	4	WR-11	4	17	0.0	0.0	0.0	0.0	0.0	0.0
1940	5	*** Beginning **	5	0		4673.0	4673.0		15037.0	15037.0
1940	5	WR-10	5	16	0.0	1247.8	1247.8	0.0	12648.2	12648.2
1940	5	WR-11	5	17	0.0	1247.8	0.0	0.0	0.0	0.0
1940	6	*** Beginning **	6	0		22485.0	22485.0		72349.0	72349.0
1940	6	WR-10	6	16	0.0	20043.5	20043.5	0.0	71219.0	71219.0
1940	6	WR-11	6	17	0.0	20043.5	20043.5	0.0	38700.1	38700.1

Note: The ZZZ file is actually much longer extending from January 1940 through December 1997.

The ZZZ file covers the entire period-of-analysis which is 1940-1997 for the example in the *Fundamentals Manual*. Only the first six months are shown in Table 6.3. The year and month are tabulated in the first two columns of the ZZZ file table. The month (M) in the second column is an integer between 1 and 12 repeating each year, and the month (M) in the fourth column is an integer between 1 and 696 covering the 696 months in the 1940-1997 period-of-analysis. The third column is the water right identifier. The sixth column with heading WR is the integer water right index with 1 denoting the most senior water right in the *SIM* input dataset. The table includes flows at control points with identifiers George and Grang.

The ZZZ table is constructed as the simulation proceeds through the water rights priority sequence each month. The default is to include all water rights in the table. However, in creating the ZZZ file of Table 6.3, a ZZ record option was used that allows specification of a minimum flow change required to include a water right in the table. A minimum limit of 0.01 acre-feet was entered on the ZZ record for this example, which essentially means a non-zero change. Thus, an additional row is added to the ZZZ file table only if at least one of the flows in the row is different from the preceding row of the table in an amount of at least 0.01 acre-feet. With a total of 30 water rights in the example, this option greatly reduces the length of the table.

Using the third month (March 1940) as an example, the ZZZ file is interpreted as follows. The purpose of the ZZZ file is to display the impacts of all water rights on regulated and available flows at each of the two control points with identifiers George and Grang. At the beginning of the water rights priority loop for the third month, prior to simulating any of the water rights, the March 1940 regulated and available flow are both 464.0 acre-feet/month at control point George and 1,493.0 acre-feet/month at control point Grang. The initial flows are always naturalized flows plus, if next-month return flow or next-month hydropower options are activated, any return flows or hydropower releases from the preceding month.

In month 3 (March 1940), one or more of the flows are affected by water rights WR-10, WR-11, WR-15, and WR-24. The relative priority rankings of these four water rights are 16, 17, 22, and 24. The 15 other rights senior to WR-10 do not affect the flows at Grang. After simulating water right WR-10, the regulated and available flows are reduced to 0.0 at George and are increased to 1,844.8 acre-feet at Grang. The increase at Grang is due to return flow from a diversion at George located upstream. Water right WR-11 reduces the regulated and available flows to zero at both George and Grang. The flows at George remain zero throughout the remainder of the priority sequence simulation. Water rights WR-15 and WR-24 increase the regulated flows at Grang to 2,141.7 and 42,661.4 acre-feet. WR-15 and WR-24 are diversions at a downstream control point for which releases are made from the reservoir at control point Grang. The reservoir release column of the ZZZ file table is a component of regulated flow, which for the 2,141.7 and 42,661.4 acre-feet flows happen to account for the total regulated flow.

With the 4ZZZ and 4ZZF input records reproduced below, *TABLES* reads the ZZZ file of Table 6.3 and creates the tables reproduced as Tables 6.4 and 6.5 which are stored in the *TABLES* output TOU file. Only tables for control point Grang are shown in Tables 6.4 and 6.5.

```
.4ZZZ  1  0  0  3  2  WR-15
IDEN  George  Grang
4ZZF  3  0  -2
```



Table 6.4  
4ZZZ Time Series Table for the Example

AVAILABLE FLOWS (AC-FT) AT CONTROL POINT Grang AFTER WATER RIGHT WR-15

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	0.0	0.0	0.0	0.0	0.0	38700.1	41287.8	0.0	0.0	0.0	61450.0	93787.7	235225.6
1941	47665.1	71520.6	65411.5	79235.1	75511.2	52022.0	9154.9	0.0	0.0	0.0	0.0	0.0	400520.4
1942	0.0	0.0	0.0	16669.8	10531.5	34323.2	0.0	0.0	0.0	13617.2	5202.0	4431.2	84774.9
1943	3690.2	762.1	1386.1	0.0	894.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6733.0
1944	0.0	0.0	16695.6	11904.1	76071.8	40817.2	0.0	0.0	0.0	0.0	0.0	0.0	145488.7
1945	8710.6	30961.5	36545.4	57386.8	20764.5	30247.0	1537.5	0.0	0.0	0.0	0.0	0.0	186153.3
1946	2333.2	19700.4	24500.5	17174.1	21782.2	2816.9	0.0	0.0	0.0	0.0	0.0	0.0	88307.3
1947	47824.1	24090.8	22910.0	17035.0	6888.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	118748.2
1948	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1949	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1951	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1952	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1953	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1954	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1955	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1956	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1957	0.0	0.0	0.0	57748.0	60822.6	76943.6	0.0	0.0	0.0	23389.1	27267.5	22420.3	268591.1
1958	20269.5	81094.1	44542.2	15465.1	19635.8	3816.3	0.0	0.0	0.0	0.0	0.0	0.0	184823.0
1959	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	80410.6	19759.1	60720.1	160889.8
1960	46932.2	37634.5	20155.5	9534.6	1557.8	0.0	0.0	0.0	0.0	0.0	11930.6	53450.1	181195.3
1961	50107.7	91158.9	27546.0	7423.2	856.9	0.0	13895.9	0.0	0.0	942.5	2199.2	2482.4	196612.7
1962	1744.3	911.0	0.0	1837.3	1503.1	3563.1	0.0	0.0	0.0	0.0	0.0	0.0	9558.8
1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1965	0.0	0.0	0.0	8642.4	114853.4	19204.5	266.1	0.0	0.0	0.0	0.0	0.0	142966.4
1966	6659.0	15905.0	12100.8	47844.8	33275.7	6862.2	0.0	0.0	0.0	0.0	0.0	0.0	122647.5
1967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1968	81538.4	35804.3	50647.1	30769.9	54905.2	30144.3	10842.7	0.0	0.0	0.0	0.0	3068.3	297720.2
1969	3142.9	11365.6	17459.1	49687.6	43873.2	4400.9	0.0	0.0	0.0	0.0	0.0	0.0	129929.3
1970	0.0	0.0	34690.2	24135.9	43064.8	14486.7	0.0	0.0	0.0	0.0	0.0	0.0	116377.6
1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1973	0.0	0.0	0.0	14490.6	28854.9	6869.1	0.0	0.0	0.0	10438.8	7636.2	0.0	68289.6
1974	11279.5	6065.6	4024.0	1876.3	43321.1	0.0	0.0	0.0	0.0	0.0	31212.2	18659.0	116437.7
1975	16018.5	69636.0	16367.9	7876.2	82738.8	38475.3	10031.4	6730.4	616.9	0.0	0.0	0.0	248491.4
1976	0.0	0.0	0.0	15827.4	40592.0	11626.5	17646.2	0.0	0.0	0.0	869.7	13032.8	99594.6
1977	9006.1	24895.4	10357.7	62683.0	22267.0	2037.6	0.0	0.0	0.0	0.0	0.0	0.0	131246.8
1978	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1979	0.0	0.0	747.0	33283.5	57798.1	41649.8	11956.4	1375.3	0.0	0.0	0.0	0.0	146810.1
1980	0.0	512.9	4124.0	2479.9	19074.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26191.7
1981	0.0	0.0	0.0	0.0	0.0	136074.1	28240.5	0.0	0.0	0.0	0.0	1877.5	166192.1
1982	1637.1	595.9	1171.6	7866.5	31890.4	9626.9	0.0	0.0	0.0	0.0	0.0	0.0	52788.4
1983	0.0	0.0	0.0	0.0	0.0	14082.0	0.0	0.0	0.0	0.0	0.0	0.0	14082.0
1984	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1985	0.0	25312.6	21349.5	13650.4	16792.7	3680.3	0.0	0.0	0.0	0.0	0.0	0.0	80785.5
1986	0.0	41366.8	6358.0	1448.6	7143.4	25233.5	0.0	0.0	0.0	1737.8	8969.7	60533.3	152791.1
1987	15532.1	20799.2	23212.9	8466.4	35306.5	148868.0	4999.1	595.1	0.0	0.0	0.0	0.0	257779.3
1988	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	0.0	0.0	0.0	23364.6	23620.5	8594.6	0.0	0.0	0.0	0.0	0.0	108390.5	163970.2
1992	90167.7	200100.3	94046.9	23436.9	61136.4	50273.7	17781.1	2492.2	0.0	0.0	0.0	7388.0	546823.2
1993	9844.1	25049.5	31405.0	22333.5	39097.1	49705.4	9685.5	0.0	0.0	0.0	0.0	0.0	187120.1
1994	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1995	0.0	0.0	15153.7	6974.1	16555.3	10306.2	0.0	0.0	0.0	0.0	0.0	0.0	48989.3
1996	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1997	727.2	26897.3	39670.0	142082.3	84805.0	83054.5	11581.9	0.0	0.0	0.0	0.0	0.0	388818.2
MEAN	8186.7	14864.5	11078.9	14493.7	20651.5	17215.6	3257.0	193.0	10.6	2070.6	3091.4	7894.4	103008.0

Table 6.5  
4ZZF Frequency Analysis Table for the Example

FREQUENCY TABLE FOR AVAILABLE FLOWS AT CONTROL POINT Grang

WATER		STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
WR	RIGHT	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
0	Beginning	15772.4	25225.	0.0	0.0	0.0	175.4	481.4	1805.0	3652.	5489.	8552.	19998.	45534.	212283.
1	IF-1	15769.9	25226.	0.0	0.0	0.0	157.6	481.4	1805.0	3652.	5489.	8552.	19998.	45534.	212283.
4	WR-1	15767.9	25227.	0.0	0.0	0.0	135.4	471.4	1805.0	3652.	5489.	8552.	19998.	45534.	212283.
5	WR-2	15767.9	25227.	0.0	0.0	0.0	135.4	471.4	1805.0	3652.	5489.	8552.	19998.	45534.	212283.
6	WR-14	15767.5	25228.	0.0	0.0	0.0	135.4	467.0	1805.0	3652.	5489.	8552.	19998.	45534.	212283.
7	WR-20	15767.2	25228.	0.0	0.0	0.0	129.4	467.0	1805.0	3652.	5489.	8552.	19998.	45534.	212283.
8	WR-22	15757.6	25233.	0.0	0.0	0.0	44.6	455.2	1780.0	3652.	5489.	8552.	19998.	45534.	212283.
9	WR-16	15756.9	25234.	0.0	0.0	0.0	22.6	447.6	1780.0	3652.	5489.	8552.	19998.	45534.	212283.
10	WR-17	15754.2	25236.	0.0	0.0	0.0	3.2	445.0	1780.0	3652.	5489.	8552.	19998.	45534.	212283.
11	WR-13	15750.3	25238.	0.0	0.0	0.0	0.0	435.8	1780.0	3652.	5489.	8552.	19998.	45534.	212283.
12	WR-19	15749.1	25239.	0.0	0.0	0.0	0.0	398.6	1780.0	3652.	5489.	8552.	19998.	45534.	212283.
13	WR-21	15743.6	25242.	0.0	0.0	0.0	0.0	341.8	1762.0	3652.	5489.	8552.	19998.	45534.	212283.
14	WR-8	15729.6	25249.	0.0	0.0	0.0	0.0	283.0	1755.0	3600.	5469.	8552.	19998.	45534.	212283.
16	WR-10	14014.6	22907.	0.0	0.0	0.0	72.0	633.5	2137.1	3740.	4946.	7594.	16014.	36328.	200743.
17	WR-11	8621.7	21301.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	4024.	30847.	200100.
18	WR-3	8609.3	21306.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	4024.	30847.	200100.
19	WR-12	8586.5	21314.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3816.	30847.	200100.
22	WR-15	8584.0	21314.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3816.	30847.	200100.
24	WR-24	8560.6	21321.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3690.	30847.	200100.
25	WR-4	8625.7	21299.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3816.	30847.	200100.
26	WR-5	8551.6	21324.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3563.	30847.	200100.

The 4ZZZ record time series table reproduced as Table 6.4 is for available stream flows at the Grang control point. The flows in the table represent flow volumes available to a right located at the Grang control point during each month of the 1940-1997 hydrologic period-of-analysis after consideration in the priority sequence simulation of water right WR-15 and all other rights that are senior to WR-15. Water right WR-15 has an integer priority rank identifier of 22 shown in Tables 6.3 and 6.5 meaning 21 other more senior rights are found in the *SIM* input. The flows in Table 6.4 represent the amount of stream flow available at control point Grang in the water rights priority sequence between water right WR-15 with a priority rank WR of 22 and water right WR-23 with rank WR of 23. Similar 4ZZZ tables can be easily created from the ZZZ file of Table 6.3 for either of the three flow variables (reservoir releases, regulated flows, available flows) at either of the two control points (George and Grang) at the beginning of the priority sequence or after simulation of either of the 22 water rights included in the ZZZ file. The flows can also be written in a columnar format for transport to a spreadsheet program or as records in a DSS file for plotting with HEC-DSSVue.

The 4ZZF frequency table of Table 6.5 was developed by *TABLES* based on computing the mean and standard deviation (Equations 5.6 and 5.7) and applying the relative frequency formula (Equation 5.3) similarly as for the 2FRE frequency table of Table 5.12 of Chapter 5. A 4ZZF record frequency table is developed from the ZZZ file for a selected variable at a selected control point. With no specific month such as August specified, all 696 months of the 1940-1997 simulation are included in the computations. The available flows after considering water right WR-15 in the priority sequence have a mean of 8,584 acre-feet/month, and a volume of 3,816 ac-ft/month is equaled or exceeded during 25 percent of the months. The available flow at this point in the priority sequence is at least 30,847 ac-ft/month during ten percent of the time.

## **Beginning-Ending Storage Options**

*SIM* has several options for specifying storage content of each reservoir at the beginning of the simulation. The default beginning-of-simulation storage content is the maximum storage capacity entered on a *WS* record for a water right associated with the reservoir. Optionally, the initial storage content may be entered on the *WS* record for each reservoir. If not otherwise specified, the storage at the beginning of the simulation is set equal to the reservoir storage capacity by default.

*SIM* also includes a set of beginning-ending storage (BES) options activated by an entry on the *JO* record. The BES options provide capabilities for setting beginning storages for numerous reservoirs more conveniently than using the *WS* record for each individual reservoir. Though setting beginning storages for other types of applications may be useful as well, the beginning-ending storage (BES) feature is motivated primarily by situations in which beginning storage is set equal to ending storage.

In past Texas WAM System applications of WRAP, beginning-of-simulation reservoir storage has typically been set at capacity for all reservoirs. The hydrologic period of analysis has been selected to begin with a series of relative wet years during which the assumption of initially full reservoirs is reasonable. However, beginning-of-simulation storage may be an issue in some applications. The initial storage content less the storage content at the end of the simulation represents extra water that could result in estimated reliabilities being higher than they should.

The BES feature is based on setting beginning and ending storages equal, which reflects the concept of a cycling hydrologic simulation period. A fixed simulation period is assumed to conceptually repeat forever. For example, hydrology may be represented by a set of naturalized flows and evaporation rates covering a 1940-2007 period-of-analysis. The 68-year hydrologic sequence is assumed to repeat forever. The sequences of naturalized flows and evaporation rates starting in January 1940 are assumed to repetitively follow completion of the sequences in December 2007. Cycling results in a steady state condition with the storages at the beginning and ending of the 68 year hydrologic cycle being identical. The cycling premise is incorporated into models by setting the storages at the beginning and ending of the simulation equal.

One approach for setting the beginning and ending storages equal is to perform the simulation two or more times. The first simulation is based on assumed beginning storages, such as assuming reservoirs are full to capacity. For the second and subsequent (as needed) simulations, the beginning storage is set equal to ending storage from the previous simulation. One iteration may be sufficient to achieve the same beginning and ending storage conditions in some cases. Additional iterations may be necessary. The beginning-ending storage (BES) switch on the *JO* record activates options that are based on an initial simulation just to determine the storage at the end of the simulation. A second simulation begins with the beginning storages set equal to these ending storages. The ending storages may be recorded in a file and read as beginning storages with the process manually repeated iteratively. A second simulation may also be repeated automatically within *SIM* either with or without recording the storages in a BES file. Thus, the model user can quickly run *SIM* multiple times to iteratively determine a set of beginning storage content levels that result in the simulation ending with the same storage levels.

*SIM* also has options in which diversion return flows and hydropower releases are returned to the stream system the next month after the water supply diversion or hydropower release occurs. The BES options include a feature that also cycles the next-month option return flows and hydropower releases. The flows from the last month of the initial simulation re-enter the stream system at the beginning of the repeat simulation.

The beginning-ending storage options are selected by the parameter *BES* in *JO* record field 5. The six alternative options are as follows.

1. *BES* of 1 specifies that the storage content of each reservoir at the end of the simulation be written to a file with the filename extension BES.
2. *BES* of 2 specifies that initial storages at the beginning of the simulation be read from the BES file.
3. For *BES* = 3, the storages at the beginning of the simulation are read from the BES file, and the storages at the end of the simulation are written to the BES file. Thus, option 3 combines options 1 and 2.
4. With *BES* = 4, the simulation is performed twice; the storages at the end of the first simulation are written to the BES file; and the storages at the beginning of the second simulation are read from the BES file. Thus, the storages at the beginning of the second simulation are set equal to the storages at the end of the first simulation. The BES file contains the storages at the end of the first simulation and beginning of the second simulation. The final output file contains the results of the second simulation.
5. *BES* = 5 performs a dual simulation identical to option 5 except the BES file is not created. The storages at the end of the first simulation become the storages at the beginning of the first simulation without being written to a file.
6. *BES* = 6 creates a listing with reservoir-related water rights information added that cannot be read by *SIM*, but rather is designed just for information for the model-user.

BES options 4 and 5 also address return flows and hydropower releases. With the next-month return flow and next-month hydropower options in effect, BES options 4 and 5 return the return flows at the end of the simulation back to the beginning.

Options 1, 2, 3, and 4 involve writing ending storages to a file and/or reading beginning storages from the file. Using options 1, 2, and 3, two or more simulations may be performed by repeated runs of *WRAP-SIM*. Options 4 and 5 involve an automatic second simulation with second simulation beginning storages set equal to the storages at the end of the first simulation. Options 4 and 5 also return next-month option hydropower releases and return flows from the end of the simulation back to the beginning.

All options except option 5 require activation of a BES file, which is opened automatically. A BES file written by *SIM* includes all reservoirs listed in the conventional order established when the DAT file was read. A BES file read by *SIM* may include any number of the reservoirs but they must be listed in the order of the numeric identifiers. The BES file may be

manually edited to change storage amounts or delete/add reservoirs. A reservoir may be removed either by entering a -1 for its storage amount or by deleting its entry from the file. If a BES file is read, for any reservoirs not included in the file, beginning storages are set by WS record fields 3 and 8 in the conventional manner.

### **Tables Summarizing Water Right, Control Point, or Reservoir Input Data**

Organizing the *SIM* input data into easier-to-read tables is often useful for display and analysis purposes. Use of the program *TABLES* is covered in Chapter 4 of the *Users Manual*. Though most *TABLES* routines deal with *SIM* simulation results, *TABLES* Type 1 input records create tables that organize the data read from a *SIM* input DAT file.

A 1SUM record builds a water rights summary table with the number of rights, diversion targets, number of reservoirs, storage capacities, and priority ranges summed optionally by control point, water use type, water right type, or specified water right groupings. The 1SRT record provides a tabulation of water rights listed in priority order with pertinent data for each right. The 1SRT tabulation is typically much longer than the 1SUM table since a row of data is included for each individual water right rather than for water right groupings.

Control point data are provided on *CP* records that may be stored in the DAT input file in any order. The *TABLES* 1CPT record activates a routine that rearranges control point records in upstream-to-downstream order. The rearranged *CP* records may be written to a file with no change other than the re-sequencing. Options are also provided to build tables of pertinent information for the control points listed in upstream-to-downstream order.

The *SIM* beginning reservoir storage BRS file activated by a switch on the *JO* record is a tabulation with the following four columns: (1) reservoir identifier, (2) control point location, (3) storage capacity, and (4) beginning-of-simulation storage content. The BRS file is designed to provide beginning storage contents for program *SALT* and a *TABLES* conditional reliability modeling routine, both described in the *Supplemental Manual*. However, the reservoir storage table may also be useful for general information.

### **General Framework for Applying WRAP**

WRAP is a flexible modeling system that can be applied in various ways depending on the particular situation. Conventional strategies for applying the WRAP programs *SIM* and *TABLES* adopted in the past are briefly discussed in this section. The next and last section of this chapter outlines newer proposed approaches for combining *SIM* and *HYD* in developing hydrology datasets that have not yet been routinely applied.

The Water Availability Modeling (WAM) System discussed in Chapter 1 combines the generalized WRAP and input datasets listed in Table 1.2 for all of the river basins of Texas. Implementation of the WAM System during 1997-2003 consisted of developing input datasets and modeling a specified set of water management and use scenarios for each of the river basins. The WRAP programs were greatly expanded and improved in response to challenges encountered and experience gained in modeling the diverse individual river basins of the state.

The *SIM* and *TABLES* features outlined in this *Reference Manual* and companion *Users Manual* have been extensively applied by the water management community in Texas. Most of the features outlined in Chapters 1 through 5 of this *Reference Manual* are in routine use. However, the additional more recently developed modeling capabilities documented by the *Supplemental Manual* have not yet as of March 2008 reached the stage of being routinely applied. The WRAP features covered in the *Supplemental Manual* are purposely documented separately and are not addressed in this *Reference Manual* and accompanying *Users Manual*.

WRAP is routinely applied in regional and statewide planning studies and water rights regulatory activities in Texas using the input datasets from the TCEQ WAM System. WRAP users employed by water agencies, consulting firms, and universities modify these data files to model the alternative water resources development projects, river regulation strategies, and water use scenarios being investigated in their studies. The WAM System datasets are periodically updated by the Texas Commission on Environmental Quality (TCEQ) to reflect changes in water right permits and water management practices and refinements in modeling capabilities.

WRAP is applicable essentially any place in the world for modeling a comprehensive range of water resources development, management, and allocation practices and river/reservoir system configurations and operations. For river basins outside of Texas, model users must develop the input datasets required for their particular applications. New and different input datasets may also be developed for different types of applications in Texas.

Developing a *SIM* simulation input dataset can be a major effort. The program *HYD* is designed to assist in developing the hydrology files of stream flows and net evaporation-precipitation depths for the *SIM* input dataset. Most of the hydrology datasets for the Texas WAM System were completed prior to completion of the program *HYD*. Microsoft Excel was used for most of the computational tasks that have since been incorporated into *HYD*. The original program *WRAP-HYD* developed during 1998-2000 was significantly improved during 2007-2008. Potential new applications for *HYD* are discussed in the next section of this chapter.

A simulation study typically involves many executions of *SIM* and *TABLES* modeling alternative water resources development, management, allocation, and use scenarios. The river/reservoir system is simulated with *SIM* with the results reorganized with *TABLES* for display and analysis purposes. The primary *SIM* simulation time series results recorded in the OUT file are input to *TABLES* to perform user-specified reliability, frequency, water accounting, and other analyses. The same *SIM* simulation time series output is optionally recorded in a *SIM* DSS output file for transfer to HEC-DSSVue for plotting graphs or other analysis. Options in *TABLES* also allow *SIM* output with or without further *TABLES* adjustments to be transported to HEC-DSSVue. The simulation results may also be transferred to ArcGIS for spatial display.

The preceding Chapter 5 focuses on the time series variables of *SIM* simulation results stored in the OUT, SOU, and DSS output files and *TABLES* capabilities for reorganizing these data and performing frequency, reliability, and water budget analyses. The preceding sections of Chapter 6 discuss organization and analyses of *SIM* simulation results associated with other *SIM* output files. The following final section of Chapter 6 addresses other innovative ways of using *SIM* simulation results in an OUT file with *HYD* to further expand modeling capabilities.

## **HYD Stream Flow Adjustments Using SIM Simulation Results to Develop SIM Hydrology Datasets**

Program *HYD* capabilities are outlined in Chapter 3 of this *Reference Manual* and Chapter 5 of the *Users Manual*. *HYD* is a set of routines designed to assist in developing hydrology input datasets for *SIM*. The description of *HYD* features in Chapter 3 of this *Reference Manual* is primarily from the perspective of conventional applications in which *SIM* input files of naturalized stream flows and evaporation-precipitation depths are developed prior to application of *SIM* and thus without reference to *SIM* simulation results. The following discussion deals with special applications in which *SIM* simulation results from an OUT output file are incorporated in developing *SIM* hydrology input data. The following two types of applications are discussed.

- extension of the hydrologic period-of-analysis
- development of simplified datasets with a reduced number of control points, water rights, and reservoirs

### **Extending the Hydrologic Period-of-Analysis**

The hydrologic simulation periods for the Texas Water Availability Modeling (WAM) System datasets listed in Table 1.2 of Chapter 1 all begin in either 1934, 1940, or 1948 and end in either 1989, 1996, 1997, 1998, or 2000. As of March 2008, these original hydrologic periods-of-record had not yet been extended forward toward the present. A possible methodology for extending the naturalized stream flows is outlined in this section. The methodology is based on using an adjusted current use *SIM* input dataset from the WAM System to convert gaged stream flows to naturalized flows. The WAM System current use scenario is defined in Chapter 1. Capabilities are incorporated in *HYD* for performing the computations necessary to implement this strategy.

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

As an example to illustrate this alternative procedure, assume that the hydrologic simulation period is 1940 through 1997 for a particular river basin. Our hypothetical example dataset has about 1,000 control points of which 50 are primary control points with naturalized flows provided in the *SIM* input. The task addressed here is to develop naturalized monthly flows at the 50 primary control points for the period 1998-2007.

A proposed procedure for extending a naturalized flow dataset to cover the period 1998-2007 at pertinent primary control points consists of combining two datasets.

- 1998-2007 sequences of monthly flows at pertinent gaging stations compiled from available USGS gage records of observed daily flows
- *SIM* input DAT file representing 1998-2007 actual water management and use developed based on modifying the TCEQ WAM System current use input dataset

The procedure consists of iteratively adjusting gaged flows at USGS gaging stations with the differences between naturalized (unregulated) flows and regulated flows from a *SIM* simulation with a modified current use dataset. An iterative procedure is required because naturalized flows are computed as a function of flow adjustments but the flow adjustments are computed as a function of naturalized flows. The iterative procedure begins with a statistically based set of 1998-2007 naturalized flows determined from the 1940-1997 naturalized flows that serves the sole purpose of determining an initial estimate of flow adjustments which are later updated.

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

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

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

The difference between the naturalized flows provided as input to a *SIM* simulation and the regulated flows computed by the *SIM* simulation is the summation of stream flow depletions, return flows, reservoir releases, inflows or outflows from constant inflow *CI* records or flow adjustment *FA* records which are each appropriately cascaded to downstream control points while accounting for channel losses. Thus, the *SIM* variables represented by the differences between regulated and unregulated (naturalized) flows are defined as follows.

*stream flow depletion* – volume appropriated by a water right to meet diversion requirements and/or refill reservoir storage while also accounting for evaporation

*return flow* – portion of stream flow depletion that is returned to the stream

*reservoir releases* – those releases from reservoir storage made specifically for a water right to meet a diversion, instream flow, or refilling target at a control point located further downstream or releases for hydroelectric energy generation

other inflows – inflows representing water supply return flows, interbasin transport, or other considerations that are input on *CI* and/or *FA* records



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

Subtracting regulated flows from naturalized flows at a control point may result in positive differences in some months and negative differences in other months. The naturalized less regulated flow difference is usually positive if stream flow depletions exceed return flows and upstream reservoir releases and negative otherwise.

Regulated flows are computed from a set of naturalized flows, but regulated flows are required for the flow adjustments (naturalized – regulated flows) used to determine the naturalized flows. Thus, an iterative procedure is required. An initial set of adjustments is developed based on an initial approximation of naturalized flows. These initial flow adjustments are used to convert gaged flows to naturalized flows, which are then used to develop a better estimate of flow adjustments. Program *HYD* can be used to perform the computations.

The proposed procedure for extending a naturalized flow dataset to cover the period 1998-2007 at pertinent primary control points includes the following tasks.

1. Available gaged daily flow data for 1998-2007 at gaging stations are compiled and aggregated to monthly flows. HEC-DSSVue may be used to assist with this task.
2. A set of 1998-2007 monthly net evaporation-precipitation depths are compiled for all pertinent control points that have reservoirs.
3. An actual use *SIM* input dataset is developed that has a 1998-2007 simulation period. The original current use water rights input dataset already approximates 1998-2007 conditions of water management and use but is modified to further improve the representation of actual 1998-2007 water management/use. Although the current use DAT file may be used with minimal or no modifications, the following adjustments will improve accuracy in better representing actual 1998-2007 water management and use.
  - The upstream-to-downstream natural priority option may be adopted to replace the permit priorities. This is a simple option switch in *SIM*.
  - Beginning of 1998-2007 simulation reservoir storage volumes are compiled as follows. A *SIM* execution of the modified dataset with the 1940-1997 hydrology results in end-of-simulation December 2007 storage volumes for the many reservoirs. These amounts are used to set the beginning of January 1998 reservoir storage using the *SIM* beginning reservoir storage (BRS) option. For the larger reservoirs, available observations from gage records are used to replace the *SIM* simulated beginning of January 1998 storage volumes. These are the beginning-of-simulation reservoir storage volumes for the 1998-2007 *SIM* simulation DAT file.
  - For the larger reservoirs with readily available gaged sequences of 1998-2007 end-of-month storage volume observations, the actual storages for all months are incorporated

into the *SIM* DAT file with the type 7 storage right feature combined with *TS* record sequences of the actual 1998-2007 gaged storage volumes.

- Diversion targets and return flows in the DAT file are not changed for many of the water rights due to lack of data, the effort required to update, and minimal impact on final results. However, considering data availability, any number of the larger diversion targets and return flow specifications may be updated with actual 1998-2007 observations. The time series of updated diversions may be entered on *TS* records or alternatively representative annual targets may be entered on *WR* records.
  - Any other modifications may be made to the DAT file dataset to more closely model actual 1998-2007 water management and use.
4. A FLO file with 1998-2007 naturalized flows is required for the *SIM* input dataset. However, 1998-2007 naturalized flows are the unknown data that the overall procedure is designed to compute. An initial set of 1998-2007 naturalized flows is developed as follows solely for use in developing the initial estimate of flow adjustments. Although mean flows, median flows, or any other exceedance frequency flows could be adopted, the 75 percent exceedance frequency flows are proposed as being reasonably likely flows on the conservatively low side of mean flows. Using the 1940-1997 naturalized flows at a particular control point, the flow volume that is equaled or exceeded in 75% of the 58 years is determined for each of the 12 months January through December. The resulting set of 12 naturalized flow volumes for January–December are repeated for each of the ten years during 1998–2007.
  5. The *SIM* simulation model is executed with the 1998-2007 period-of-analysis input dataset consisting of the DAT file developed in the preceding Task 3, EVA file from Task 2, and FLO file from Task 4. The objective is to simulate regulated flows that can be used to develop an initial estimate of flow adjustments consisting of naturalized (unregulated) flows minus regulated flows at the pertinent control points.
  6. *HYD* reads the *SIM* output OUT file developed as Task 5 and the gaged flows from Task 1. The following computations are performed.
    - Flow adjustments are computed as the difference in naturalized flows minus regulated flows read by *HYD* from the *SIM* output OUT file.
    - Naturalized flows are computed by subtracting the flow adjustments from the gaged flows read by *HYD* from another *HYD* input file in either text file or DSS file format.

Task 6 results in a set of 1998-2007 naturalized flows at the pertinent primary control points. The naturalized flows are approximate since the flow adjustments were determined based on the 1998-2007 naturalized flow dataset developed as Task 4 which are statistically based on 1940-1997 historical flows rather than adjustments to 1998-2007 actual gaged flows.

7. The naturalized flows developed in Task 6 above are stored as a FLO or DSS file which replaces the FLO or DSS file used in Task 5 above. *SIM* is executed again to obtain an updated set of regulated flows which when differenced with the corresponding latest update of naturalized flows provides a better estimate of flow adjustments.

8. *HYD* is run again with the new *SIM* output file from Task 7 and the original gaged flows from Task 1. The following computations previously performed in Task 6 are repeated.
  - Flow adjustments are computed by subtracting regulated flows from naturalized flows read by *HYD* from the *SIM* output OUT file.
  - Naturalized flows are computed by subtracting the flow adjustments from the gaged flows.

The result is a FLO or DSS file with the final naturalized flows for 1998-2007.

### Developing a Simplified Input Dataset

The larger Texas WAM System datasets listed in Table 1.2 of Chapter 1 contain hundreds of water rights, control points, and reservoirs. These large complex datasets are necessary for the regional and statewide planning and water right permitting applications for which the datasets were developed. However, simpler datasets are advantageous for certain other applications. A methodology is presented here for simplifying *SIM* input datasets for particular applications. Selected water rights, control points, and reservoirs are removed with their effects retained in the adopted stream inflow input data for the simplified dataset.

For example, assume that a large *SIM* input dataset contains 1,650 diversions, 510 reservoirs, and 2,150 control points. Naturalized flows are input on inflow *IN* records for 32 primary control points located at gaging stations and distributed within *SIM* to the other 2,118 ungaged secondary control points. The hydrologic period-of-analysis is 1940-2006.

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

The objective is to develop a simplified *SIM* input dataset for purposes of studying or providing decision support for a particular system, which in this example consists of ten reservoirs and 25 diversions with associated river/reservoir/use system operating rules. The motivation is simply that input datasets and corresponding output datasets with dramatically fewer control points, water rights, and reservoirs are much more manageable to use in modeling studies. The simplified dataset in our example consists of the following *SIM* input files.

- DAT file with information for ten reservoirs and 25 diversions at 15 control points
- FLO or DSS file with 1940-2006 sequences of monthly flows representing conditions of river system development that includes all of the water rights and associated reservoirs in the original complete DAT file except the 25 diversions and ten reservoirs contained in the simplified dataset DAT file
- EVA or DSS file with 1940-2006 sequences of monthly net evaporation-precipitation depths for the ten control points at which the ten reservoirs are located

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

The accuracy achieved in the development of a simplified dataset can be checked by comparing simulation results with the original complete dataset. The monthly diversion amounts and reliabilities computed for the diversions included in the simplified dataset should be the same as in the simulation with the original complete dataset. Likewise, the 1940-2006 sequences of monthly reservoir storage volumes and regulated and unappropriated stream flows at the 15 control points will be the same. Near perfect correspondence between simulation results with the simplified versus complete datasets should be expected.

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

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

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

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

The methodology for developing the stream flow data (FLO or DSS file) for the simplified dataset is outlined as follows.

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

Referring again to the example, stream flows developed for the 15 control points consist of the following 1940-2006 sequences of monthly volumes of the following variables obtained from the OUT file created by *SIM* with the original complete input dataset. The computations can be performed with *HYD*.

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

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

## CHAPTER 7 DETECTING ERRORS AND IRREGULARITIES IN DATA FILES

Blunders are inevitable in compiling voluminous input datasets. Detecting and correcting input errors is fundamental to computer modeling. The WRAP programs include features designed to help detect missing and erroneous records in input files. The modeling system features outlined in this chapter facilitate finding many types of errors that violate format rules or result in detectable inconsistencies. However, the discussion in this chapter does not pertain to those situations in which incorrect simulation results are obtained from reasonable but wrong numbers being input in the proper format.

The following features of *SIM*, *TABLES*, and *HYD* facilitate locating errors.

- tracking of progress in reading input and performing computations
- error messages accompanied by termination of program execution
- warning messages alerting users to possible peculiarities without stopping execution

The system for tracing progress and for checking and reporting errors and irregularities is similar in all of the WRAP programs. An array of checking routines is coded into the programs that write error and warning messages. Program execution is terminated in conjunction with error messages but continues with warning messages. The programs all create message files that should be routinely examined by model users.

### Locating Errors in SIM Input Data

The progress of the *SIM* simulation is tracked by trace messages written to the monitor and message MSS file. Simulation results are written to the OUT file as computed, providing a mechanism for detailed tracking of the simulation computations. Numerous error and warning checks automatically detect irregularities in input data.

#### Tracking Simulation Progress

The following features trace the progress of the *SIM* simulation.

- Messages appearing on the monitor during model execution provide a general overview of simulation progress.
- Input trace messages written to the message file confirm that various input records were read and various other tasks were accomplished.
- The OUT output file shows intermediate results of the simulation computations.

*SIM* execution begins with an interactive session, which may be managed through *WinWRAP*, in which the roots of the filenames are entered and the files are opened. The program checks to confirm that the specified files do exist. If an input file is missing, a message to that effect appears on the monitor, and execution is terminated. An optional feature alerts the user if files with the output filenames already exist. The program requests verification from the user that these files are to be overwritten. The messages shown in Table 7.1 then appear on the

monitor as the simulation is performed. Other similar messages related to specific modeling options appear only if those options are being used.

Table 7.1  
SIM Trace Messages on Monitor

---

```
Root of input and output file names is entered
Root of hydrology file names is entered
Opening input file:  root.DAT
Opening output file: root.MSS
Reading the input data from file root.DAT
  ___ control points
  ___ water rights
  ___ reservoirs
Opening input file:  root.FLO
Opening input file:  root.EVA
Opening input file:  root.DIS
Opening input file:  root.OUT
Sorting water rights in priority order
Performing simulation for year _____
Performing simulation for year _____
  (repeated for each year)
Performing simulation for year _____

Input File:  root.DAT
Output File: root.OUT
Message File: root.MSS

***** Normal Completion of Program WRAP-SIM *****

Exit WRAP-SIM
```

---

*SIM* contains numerous error check routines that result in messages if erroneous or missing data are detected in the input files. WRAP programs all have the same general format for reporting the detection of errors. An error message describing the problem is written to the message file. All error messages result in stopping program execution. The following message is written to the monitor.

```
*** Execution of SIM terminated due to an input error.
*** See message file.
```

Progress in reading the input data is tracked by information written to the message file, which for *SIM* has the filename extension MSS, showing which records were successfully read. The MSS file trace will vary depending on the input records that are included in the dataset.

However, if the entire DAT and DIS input files and the first year of *IN* and *EV* records are read without interruption, the pertinent messages shown in Table 7.3 plus perhaps others will be generally found in the message file. If model execution is prematurely terminated, the last notation in the input trace message listing provides the approximate location in the input files at which a problem occurred. The problem input file record will be after those records confirmed as having been read successfully. The error message will be written to the message file at the end of the trace.

### JD Record ICHECK Options

Optional levels of input data traces are specified by input variable *ICHECK* in field 4 of the *JD* record. The types of information copied to the message file with each value of *ICHECK* are shown in Table 7.2.

Table 7.2  
Information Recorded in Message File for Various Values of *ICHECK*

---

<i>ICHECK</i> = 0	Trace messages shown in Table 7.3 are written to MSS file. Some error detection routines and most of the warning messages are deactivated.
<i>ICHECK</i> = 1	Table 7.3 trace messages and all error and warning routines are in effect.
<i>ICHECK</i> = 2	Table 7.3 trace messages plus all <i>UC</i> and <i>RF</i> records are written as read.
<i>ICHECK</i> = 3	Table 7.3 trace messages plus all <i>CP</i> records are written as read.
<i>ICHECK</i> = 4	Table 7.3 trace messages plus all <i>WR</i> and <i>IF</i> records are written as read.
<i>ICHECK</i> = 5	Table 7.3 trace messages plus all <i>SV</i> and <i>SA</i> records are written as read.
<i>ICHECK</i> = 6	Table 7.3 trace messages plus all <i>IN</i> and <i>EV</i> records are written as read.
<i>ICHECK</i> = 7	Table 7.3 trace messages plus all <i>FD</i> , <i>FC</i> , and <i>WP</i> records written as read.
<i>ICHECK</i> = 8	Table 7.3 trace messages plus all dual simulation information.
<i>ICHECK</i> = 9	Table 7.3 trace messages and most error checks are in effect.
<i>ICHECK</i> = 10	Trace written to MSS file for conditional reliability modeling showing the sub-division of the hydrologic period-of-analysis into multiple sequences.

---

An *ICHECK* of 0 or 1 is usually adopted. An *ICHECK* of 1 activates all error and warning checks. After a number of runs of *SIM* with a particular dataset repeatedly generating a long list of warning messages, the model-user may prefer to deactivate the warning messages by switching *ICHECK* to 0. Most of the *ICHECK* options include the MSS file trace messages shown in Table 7.3. An *ICHECK* value of from 2 to 7 results additionally in the copying of a specified set of input records to the MSS file as they are read. If program execution is terminated, the error messages discussed in the next section will usually provide sufficient information to identify the problem without needing to resort to the *ICHECK* options 2–7. However, options 2 through 7 are sometimes useful in locating an erroneous input record. *ICHECK* option 8 writes information to the MSS file that is developed by routines activated by the *PX* record. *ICHECK* option 10 outlines the hydrologic sequences generated by a conditional reliability record, which is covered in the *Supplemental Manual*.



Table 7.3  
SIM Trace Messages Written to Message File

---

WRAP-SIM MESSAGE FILE

```

*** Starting to read file root.DAT.
*** JD record was read.
*** JO record was read.
*** Starting to read UC records.
*** Finished reading UC records.
*** Starting to read CP records.
*** Finished reading CP records.
*** Starting to read IF/WR records.
*** Finished reading IF/WR records.
*** Starting to read SV/SA records.
*** Finished reading SV/SA records.
*** Finished reading file root.DAT.
*** Starting to open remaining files.
*** Opened file root.FLO
*** Opened file root.EVA
*** Opened file root.DIS
*** Opened file root.OUT
*** Finished opening text files.
*** Starting to read FD/WP records from file root.DIS.
*** Finished reading ___ FD and ___ WP records.
*** Determined watershed parameters for ___ control points.
*** Finished ranking water rights in priority order.
*****
System components counted from input file:
___ control points (CP records)
___ primary control points (INMETHOD=1)
___ reservoirs
___ instream flow rights (IF records)
___ all water rights except IF rights (WR records)
___ system water rights
___ hydropower rights
___ sets of water use coefficients (UC records)
___ storage-area tables (SV/SA records)
___ storage-elevation tables (PV/PE records)
___ drought indices (DI records)
___ dual simulation rights
___ maximum upstream gaged cpts on FD records
*****
*** Beginning annual loop.
*** ___ IN and ___ EV records were read for the first year (___)
*** Flow distribution was performed for the first year.
*** Negative incremental flow adjustments were performed for the first year.
*** End of input data trace.

***** Normal Completion of Program WRAP-SIM *****

```

---

An *ICHECK* of one should normally be selected whenever a new or revised dataset is initially run. If the model runs correctly, changing *ICHECK* to zero (blank *JD* record field 4) will save a little computer time by not performing the more time-consuming error checks and deactivating most warning messages. With *ICHECK* option 1, warning messages may be repeated numerous times resulting in a large MSS file, which may be prevented by switching to option zero. For *ICHECK* options 2 through 8, most of the error checks for *ICHECK*=1 are in effect. However, most warning message checks and several of the error checks are in effect only if *ICHECK* is one. An *ICHECK* of 9 or 10 will deactivate many warning messages without affecting error checks.

Program execution may be terminated due to a problem in an input record. Error messages normally provide sufficient information to locate the problem without the *ICHECK* options 2 through 7 input record reproduction routines noted in Table 7.2. However, *ICHECK* options 2–7 provide an additional tool to facilitate finding an erroneous record. *SIM* reads all the records in sequential order starting with the DAT file. The *ICHECK*=1 trace is used to find the general location of the problem record based on where the trace stops with an error message. The program is then rerun with a different *ICHECK* value to check which records in the groups cited in Table 7.2 are read and copied correctly.

With *ICHECK* options 2 through 7, the records are written to the MSS file immediately after each record is read. The records are copied to the MSS file almost verbatim as read, except most real numbers are written in a F8.0 Fortran format with zero digits to the right of the decimal point. If the program reads some but not all records of a particular record type, the problem will typically be associated with either the last record read and copied to the MSS file or more likely the next record in the input file. The types of records listed in Table 7.2 account for many but not all of the records in a *SIM* input set. *ICHECK*=6 applies to *IN/EV* records stored in DAT, FLO/EVA, or DSS files but does not apply to a input file with filename extension HYD.

*ICHECK* option 8 relates to the *PX* record dual simulation option. *ICHECK*=8 writes a list of rights with the dual option activated by the *PX* record and the array of initial simulation stream flow depletions for rights with *DUAL* options of 3 or 4.

Simulation results are written to the main output file (filename extension OUT) both as each individual water right is considered in the priority loop and at the end of each simulation month upon completion of the water rights priority loop. Thus, if execution is terminated after the input is read and the simulation computations begin, the computations can be tracked to approximately the point just before the computational problem. The OUT or SOU file may also be useful in analyzing computational problems that do not terminate execution.

### Error and Warning Messages

All of the WRAP programs have a similar system for managing error and warning checks. Error messages are always accompanied by automatic termination of program execution, but execution continues with warning messages. Various error checks are performed as the input files are read and the simulation computations are performed. If data are missing or in the wrong format or inconsistencies are detected, program execution is stopped and an error

message is written to the message MSS file. Warning messages identify potential problems and are also written to the message file, but program execution is not terminated. Warning routines simply write messages without affecting the simulation. Thus, the message file should be checked for warning messages even if the program runs to a normal completion.

Error messages in all of the WRAP programs are written with two components. First an individualized statement written to the message file provides information regarding the particular type of error detected. Then a standard message is written to both the monitor and message file followed by termination of program execution. Error messages in all of the programs are generated in two different ways:

1. The Fortran input/output status specifier *IOSTAT* is included in essentially all of the read statements.
2. Numerous other specific error check algorithms are coded into various data input and computational routines.

If violation of a Fortran rule is indicated by the *IOSTAT* variable in a read statement, messages are written to the monitor and MSS file along with the program being terminated. *IOSTAT* errors result in variations of the following message being written to the monitor.

```
*** Execution of SIM terminated due to an input error.  
*** IOSTAT status variable (error code) = ____  
*** ____ record contains data in wrong format.  
*** End of file was reached without finding data record.  
*** End of ____ record was reached without finding data.  
*** See message file.
```

The first and last line of the message are displayed on the monitor with any error. The second and one of the three or similar lines are added for *IOSTAT* errors. When *IOSTAT* errors occur in reading the DAT file, the following message may be written to the message file along with the last two records read.

```
ERROR: Fortran IOSTAT error occurred reading an input record with identifier CD of ____  
IOSTAT status variable = ____  
The first 82 characters of each of the last two records read are as follows:
```

The monitor and MSS file messages indicate the value for the *IOSTAT* variable as defined within the Fortran language compiler. A negative one (-1) means the end of file was reached without finding the data record. A -2 indicates the end of the record was reached without finding the data. A positive integer refers to Fortran error condition messages provided by the compiler. The most common values for the *IOSTAT* variable are 61 and 64, which mean input data is in the wrong format, such as a letter in a real or integer numeric field or a decimal in an integer field.

Many other error checking routines are coded into *SIM* with error or warning messages that are written to the message file. Error messages are accompanied by termination of model

execution. Warning messages do not stop the model or in any way affect the simulation. Many of the error and warning messages are listed in Tables 7.4 and 7.5. Other messages not included in Tables 7.4 and 7.5 have formats similar to those shown.

The checks associated with error and warning messages take various forms. For example, essentially any identifier connecting records are checked to verify that they are on the other record. The control point identifiers on *WR*, *IF*, *CI*, *SO*, *FS*, *TO*, *ZZ*, *FD*, and *WP* records are checked to ascertain that they match identifiers on the *CP* records. Likewise, water use identifiers on *WR* records are matched against those on the *UC* records. Reservoir identifiers on *SV*, *PV*, *MS*, *EA*, and *DI* records are checked to ascertain that the reservoirs have been entered on *WS* reservoirs. Upstream control points on *FD* records must actually be upstream of the specified control point as defined by *CP* records. Checks are made on certain numerical data entries to ascertain that the numbers fall within appropriate ranges. Some checks involve detecting missing records or data. Other types of checks are illustrated as well in Tables 7.4 and 7.5. *WRAP-HYD* provides additional checking of *IN* and *EV* records discussed later in the *HYD* section of this chapter.

Since error and warning messages are written as problems are detected along with the trace messages, their approximate originating location in the model is evident. As previously discussed, all error and warning checks are in effect for *ICHECK* (*JD* record field 4) of one. If option 1 is not selected for *ICHECK*, most warning checks and some of the error checks requiring the most computer time are not activated.

Table 7.4  
SIM Error Messages

---

Written to Monitor from Subroutine FILINI before opening MSS File

ERROR: Can not combine HYD with FLO/EVA files.

Written to MSS File from main program while performing simulation

ERROR: CP output written for \_\_\_ control points but expecting \_\_\_  
ERROR: TOTARGET of \_\_\_ on TO record is not valid. Water right: \_\_\_\_\_  
ERROR: TOTARGET=10 can not be combined with TOCOMB=LIM. Water right: \_\_\_\_\_  
ERROR: The ID of \_\_\_ for reservoir \_\_\_\_\_ from BES file should be \_\_\_\_\_  
ERROR: Reservoir \_\_\_\_\_ from EA record could not be matched with WS record reservoir identifiers.  
ERROR: Reservoir \_\_\_\_\_ could not be matched with EA record reservoir.  
ERROR: Reached end of file without finding ED record.

Written to MSS File from Subroutine READDAT which reads DAT File

ERROR: Read inappropriate record with CD of \_\_\_  
ERROR: Missing JD record.  
ERROR: Number of years on JD record field 2 must be at least one.  
ERROR: ADJINC of \_\_\_ and NEGINC of \_\_\_ on JD record are not compatible.  
ERROR: ADJINC of \_\_\_ on JD record is not valid.  
ERROR: EPADJ of \_\_\_ in JD field 10 is not valid.  
ERROR: IDSET of \_\_\_ in JD field 12 is not valid.  
ERROR: INEV of \_\_\_ on JO record is not valid.  
ERROR: SYSOUT of \_\_\_ on JO record is not valid.  
ERROR: PASS2 of \_\_\_ on JO record is not valid.

---

Table 7.4 SIM Error Messages (Continued)

---

ERROR: BES = ___ in JO field 5 is not valid.
ERROR: BRS = ___ in JO field 6 is not valid.
ERROR: CR1 on CR record must be greater than zero.
ERROR: CR2 on CR record must be a month between 1 and 12. Read CR2 of ___
ERROR: On CR record, CR1 of ___ is invalid with nonzero CR2 of ___
ERROR: The FY record water right identifier did not match any water right on WR records.
ERROR: FYIN(2) and FYIN(3) on FY record must be positive nonzero numbers. Read: _____
ERROR: The incremental decreases on FY record must each be less than previous level. Read: _____
ERROR: The FY record water right identifier matched ___ water rights on WR records which exceeds the dimension limit of 100.
ERROR: WO record missing. Read CD = ___
ERROR: GO record missing. Read CD = ___
ERROR: RO record missing. Read CD = ___
ERROR: CO record missing. Read CD = ___
ERROR: Missing WO, GO, RO, or CO record.
ERROR: Use identifier ___ from UP record matches no identifier on UC records.
ERROR: Read CD of ___ when expecting CP records.
ERROR: Read inappropriate CD of ___ after or within CP records.
ERROR: Missing (UC, CP) record. Read CD of _____
ERROR: Control point _____ has an invalid INMETHOD of ___
ERROR: Downstream control point identifier [CPID(cp,2)] _____ on CP record for _____ matches no CPID(cp,1).
ERROR: Identifier _____ assigned to both control points ___ and ___
ERROR: Control point identifier ___ from (CI,WR,IF,SO,FS,PX) record ___ matches no control point identifier on CP records.
ERROR: Water use identifier _____ from WR or IF record matches no identifier on UC records.
ERROR: Invalid Type of ___ in WR field 6 for water right _____
ERROR: IFMETH of ___ is not valid. IF right _____
ERROR: Return flow identifier _____ from WR record ___ matches no identifier on the RF records.
ERROR: Invalid RFMETH of ___ in WR field 7 for water right _____
ERROR: Water rights _____ and _____ associated with reservoir _____ do not have cumulative storage capacities with respect to priorities.
ERROR: Subroutine READDAT set MAXSWR at ___ but tried to read WR/IF records for at least ___ system rights, indicating a problem with hydropower or multireservoir rights.
ERROR: IFMETH = 3 or 4 but there is no reservoir (WS record) for IF right _____
ERROR: BU of ___ on BU record is not valid. Right _____
ERROR: BUWRID of _____ for right _____ matches no WRID on WR or ID records.
ERROR: BUG of _____ for right _____ matches no WRIDS on WR or ID records.
ERROR: SO record field 6 is limited to blank or BACKUP, BFIRST, or RETURN. Read: _____
ERROR: ISHT of ___ in SO record field 9 is invalid.
ERROR: TO record field 10 is limited to blank or CONT. Read: _____
ERROR: TOTARGET of ___ is not valid. Water right _____
ERROR: TOTARGET=10 combined with TOCOMB=LIM is not valid. Water right: _____
ERROR: Reservoir identifier is missing from TO record field 8 for water right _____.
ERROR: Water right identifier is missing from TO record field 9 for water right _____.
ERROR: Reservoir _____ entered in field 8 of a TO record is not on any WS record.
ERROR: Water right _____ entered in field 9 of a TO record is not on any WR record.
ERROR: TOCOMB of ___ on TO record is not valid. Water right: _____
ERROR: Read CD of ___ instead of TO for a continuation TO record for water right: _____
ERROR: Upper bound of ___ is less than lower bound of ___ on FS record. Right _____
ERROR: Invalid FSV of ___ in FS field 2 for water right _____
ERROR: FS record multiplier factors are both blank or zero for right _____
ERROR: FS record field 9 is not used without an ending month in field 10. Right: _____

---

Table 7.4 SIM Error Messages (Continued)

---

ERROR: FS record field 10 is not used without a beginning month in field 9. Right: \_\_\_\_\_

ERROR: TS record is not valid for year \_\_\_ for water right \_\_\_\_\_ CD, TSYR1, TSYR2 read as follows: \_\_\_\_\_

ERROR: \_\_\_ read for TSL from TS record is not valid. Water right: \_\_\_\_\_

ERROR: \_\_\_ for K is TSR record field 2 is not valid. Water right: \_\_\_\_\_.

ERROR: Invalid XP option of \_\_\_ on PX record field 5 for water right \_\_\_\_\_

ERROR: Invalid XPR option of \_\_\_ on PX record field 6 for water right \_\_\_\_\_

ERROR: PX record priority of \_\_\_ is less than WR record priority of \_\_\_ for water right \_\_\_\_\_

ERROR: DUAL is 5 for water right \_\_\_\_\_ but there is no preceding dual option 4 right.

ERROR: DUAL of \_\_\_ is invalid for water right \_\_\_\_\_

ERROR: Invalid XCP option of \_\_\_ on PX record field 3 for water right \_\_\_\_\_

ERROR: XCPID missing in PX record field 4 for water right \_\_\_\_\_

ERROR: The number of system reservoirs (WS records) exceeds MAXSYS of \_\_\_ for right \_\_\_\_\_

ERROR: Reservoir \_\_\_\_\_ on (MS,DI,EA) record is not on any WS record.

ERROR: WS record is not compatible with TQ/TE record for reservoir \_\_\_\_\_

ERROR: Missing (SV/SA,PV/PE,TQ/TE) record. Read CD of \_\_\_\_\_

ERROR: Missing or duplicate reservoir ID found while reading (SV/SA, PV/PE,TQ/TE) records.

ERROR: The drought index DINDEXT from the WR/IF record is \_\_\_ for right \_\_\_ but there are only \_\_\_ DI records.

ERROR: EMPTY of \_\_\_ on DI record is not valid.

ERROR: Reservoir \_\_\_ on DI record is not on any WS record.

ERROR: Number of reservoirs on DI record must be 1 to 12 or all (-1).

ERROR: Read CD of \_\_\_ when expecting EF.

ERROR: Reservoir \_\_\_ on EA record is not on any WS record.

ERROR: Reservoir \_\_\_ on EA record has EAR of \_\_\_ on WS record.

ERROR: Reservoir \_\_\_ has EAR of \_\_\_ on WS record but has no EA record.

ERROR: NEAF of \_\_\_ in EA field 3 is invalid.

ERROR: EF record is used only if NEAF is 3 or 4 in EA field 3.

ERROR: EAO is EF field 2 should be between 0 and 4. Read \_\_\_

ERROR: No SV/SA records are assigned to reservoir \_\_\_ on EA record.

ERROR: EAO of 3 or 4 in EF field 2 is valid only for NEAF of 4 in EA field 3.

ERROR: CD of \_\_\_ is used only in SIMD, not SIM.

ERROR: Number of control points and water rights must be at least one.

ERROR: Inappropriately reached end-of-file while reading DAT file. The last CD read by Subroutine READDAT was \_\_\_\_\_

ERROR: The following invalid record identifier (CD in field 1) was read: \_\_\_\_\_ This indicates either an incorrect CD, a missing record, or a blank record. The first 80 characters of each of the last two records read are as follows.

*Written to MSS File from Subroutines INEV1 and INEV2 which read IN and EV records*

ERROR: In reading (IN,EV) records, read control point ID of \_\_\_ when expecting \_\_\_\_\_

ERROR: In reading (IN,EV) records for control point \_\_\_ for year \_\_\_ read FYR of \_\_\_\_\_

ERROR: IN records were read for CP \_\_\_ but INMETHOD = \_\_\_ on CP record.

ERROR: EV records were read for CP \_\_\_ but CPEV = \_\_\_ on CP record.

ERROR: (CPIN, CPEV) in field (7, 8) of CP record for \_\_\_\_\_ was not found.

*Written to MSS File from Subroutine INEVYR which reads IN and EV records*

ERROR: In reading first IN record for first year \_\_\_ read NYR of \_\_\_ and INLYR of \_\_\_\_\_

ERROR: In reading first IN record for first year, read CD of \_\_\_\_\_ instead of IN.

ERROR: In reading IN records for control point \_\_\_ for year \_\_\_ read INLYR of \_\_\_\_\_

ERROR: In reading EV records for control point \_\_\_ for year \_\_\_ read EVLYR of \_\_\_\_\_

ERROR: In reading (IN,EV) records for year \_\_\_ a CD of \_\_\_ was read.

ERROR: (IN,EV) record was not found for year \_\_\_ for control point identifier \_\_\_\_\_

---

Table 7.4 SIM Error Messages (Continued)

---

ERROR: (CPIN, CPEV) in field (7, 8) of CP record for \_\_\_\_\_ was not found.

*Written to MSS File from Subroutine IACNP which reads DIS File*

- ERROR: Found CD of \_\_ in the DIS file, when expecting FD, FC, or WP record.  
 ERROR: \_\_\_\_\_ from field 2 of FD record \_\_\_\_\_ matches no control point identifier on CP records.  
 ERROR: Upstream gage identifier \_\_\_\_\_ from FD record \_\_\_\_\_ matches no control point identifier on CP records.  
 ERROR: \_\_\_\_\_ on the \_\_ WP record matches no control point identifier on CP records.  
 ERROR: On FD record for \_\_\_\_\_ the upstream gage \_\_\_\_\_ is not upstream of the downstream gage \_\_\_\_\_  
 ERROR: NG is -1 on FD record for \_\_\_\_\_ but the source gage \_\_\_\_\_ is not upstream of the ungaged control point.  
 ERROR: Upstream control point UGID(I) of \_\_\_\_\_ is repeated twice on FD record for CP \_\_\_\_\_  
 ERROR: The downstream gaged source control point associated with ungaged CP \_\_\_\_\_ is missing or not specified on a FD record.  
 ERROR: The drainage area for CP \_\_\_\_\_ is missing, zero, or negative: \_\_\_\_\_  
 ERROR: The incremental drainage area for CP \_\_\_\_\_ is zero or negative: \_\_\_\_\_

*Written to MSS File from Subroutine FLDIST which performs flow distribution computations*

- ERROR: NRCS CN method can not be applied for zero or negative drainage area for CP \_\_\_\_\_  
 ERROR: Gaged CP \_\_\_\_\_ is not downstream of ungaged CP \_\_\_\_\_ as required by INMETHOD (6,8)

*Written to MSS File from Subroutine LINEAR which performs linear interpolation*

- ERROR: Table number must be a positive integer. Table number of \_\_\_\_\_ associated with water right \_\_\_\_\_  
 Stopped in linear interpolation subroutine.

*Written to MSS File from Subroutine DROUGHT which develops drought index*

- ERROR: Interpolation of drought index \_\_\_\_\_ is out of range.

*Written to MSS File from Subroutine FLOWADJ which reads FAD file and adds FA record flows*

- ERROR: Control point identifier \_\_\_\_\_ in FAD file matches no control point identifier on CP records.  
 ERROR: Computations terminated due to error in FAD file. Error occurred at control point \_\_\_\_\_ during year \_\_\_\_\_
- 

Table 7.5  
SIM Warning Messages

---

*Written to MSS File from main program while performing simulation*

- WARNING: The beginning of simulation storage specified for reservoir \_\_\_\_\_ exceeds its capacity.  
 The initial storage is set at the capacity.  
 WARNING: The BES beginning storage of \_\_\_\_\_ for reservoir \_\_\_\_\_ exceeds its capacity of \_\_\_\_\_  
 WARNING: An HRR file has been created but no system water rights are specified.  
 WARNING: The TOCOMB=DIV option for right \_\_\_\_\_ involved dividing by zero and thus was skipped.  
 WARNING: Evaporation volume has wrong sign. \_\_\_\_\_  
 WARNING: PASS2 on JO record is 2, but there are no IF records.  
 WARNING: A -1.0 in output file indicates format limit exceeded. Year: \_\_\_\_\_ CP: \_\_\_\_\_  
 WARNING: JD field 4 ICHECK is 8 but there are no dual simulation rights (PX record).

*Written to MSS File from Subroutine READDAT which reads the DAT File*

- WARNING: The water right type WRNUM(wr,5) for an IF record right is automatically set at 2 meaning reservoir storage is not refilled. A type of \_\_\_\_\_ entered on the IF record was changed to 2 for IF right: \_\_\_\_\_  
 WARNING: A next-month return flow option is used with PX record field 6 option for water right \_\_\_\_\_  
 WARNING: A non-zero XPR does not pertain to XP option 1 (PX record fields 6 and 7). water right \_\_\_\_\_
-

Table 7.5 SIM Warning Messages (Continued)

- 
- WARNING: The format of the WS record used with water right \_\_\_\_\_ has been replaced with the new WS/HP record format but still works.
- WARNING: Read HP record but type is \_\_\_ for right \_\_\_\_\_
- WARNING: Energy limit of \_\_\_ in HP record field 7 is less than WR record target of \_\_\_ for water right \_\_\_\_\_
- WARNING: No storage capacity on WS record for reservoir \_\_\_ right \_\_\_\_\_
- WARNING: Inactive storage of \_\_\_ exceeds capacity of \_\_\_ for water right \_\_\_\_\_
- WARNING: Beginning storage of \_\_\_ exceeds capacity of \_\_\_ for water right \_\_\_\_\_
- WARNING: EA record should be used only with type 1 rights. \_\_\_\_\_ is type \_\_\_
- WARNING: An OR record may be inappropriate for water right \_\_\_\_\_ OR records are not used with single-reservoir type 1 or hydropower rights or with the first reservoir for these type rights with multiple reservoirs since storage is refilled in the first reservoir.
- WARNING: Water rights \_\_\_\_\_ and \_\_\_\_\_ at reservoir \_\_\_ have storage capacities that are inconsistent with priorities. A junior right can not have a smaller cumulative storage capacity than a senior right at the same reservoir.
- WARNING: Control point ID of a reservoir is missing for multiple-reservoir system right \_\_\_\_\_
- WARNING: The water right and reservoir normally should be at the same control point for a type 1 right.  
Reservoir: \_\_\_\_\_ Water right: \_\_\_\_\_
- WARNING: There is a reservoir (WS record) but IFMETH is not 3 or 4 for IF right \_\_\_\_\_
- WARNING: SV/SA records are provided but not assigned to a reservoir.
- WARNING: PV/PE records are provided but not assigned to a reservoir.
- WARNING: Missing storage-area or elevation table.
- WARNING: TQ/QE records are provided, but not assigned to a reservoir. Reservoir ID = \_\_\_\_\_
- WARNING: Incorrect NDI identifier in field 2 of DI record.
- WARNING: EAL on EF record should be between 0.0 and 1.0. Read \_\_\_\_\_
- WARNING: EF record EAF of \_\_\_ for last reservoir listed on EA record is not used.
- WARNING: Incorrect NEA identifier in field 2 of EA record.
- WARNING: XPR is \_\_\_ on PX record for run-of-river water right: \_\_\_\_\_
- WARNING: \_\_\_ on CO record is not on any CP record.
- WARNING: \_\_\_ on WO record is not on any WR record.
- WARNING: \_\_\_ on GO record is not on any WR record.
- WARNING: \_\_\_ on RO record is not on any WS record.
- WARNING: No WR/IF records have drought indices but there are \_\_\_ DI records.
- WARNING: \_\_\_ rights have drought indices ranging from \_\_\_ to \_\_\_ and MAXDI is \_\_\_\_\_
- WARNING: Inconsistency in water right counts. NWRTS is \_\_\_ and MAXWR is \_\_\_\_\_
- WARNING: Inconsistency in control point counts. NCPTS is \_\_\_ and MAXCP is \_\_\_\_\_
- WARNING: Inconsistency in reservoir counts. NRES is \_\_\_ and MAXWS is \_\_\_\_\_
- WARNING: Inconsistency in SV/SA table counts. NTABLE is \_\_\_ and MAXTAB is \_\_\_\_\_
- WARNING: Inconsistency in PV/PE table counts. NTABLE is \_\_\_ and MAXTAB is \_\_\_\_\_
- WARNING: A HRR file is activated, but there are no system water rights.

Written to MSS File from Subroutine FLOWADJ which reads the FAD File

- WARNING: Year \_\_\_ not found in FAD file.

Written to MSS File from Subroutine LINEAR which performs linear interpolation

- WARNING: Interpolation routine exceeded range of table \_\_\_\_\_  
max X = \_\_\_\_\_ given X = \_\_\_\_\_ Y = \_\_\_\_\_ max Y = \_\_\_\_\_

Written to MSS File from Subroutines INEVYR, INEV1, and INEV2 which read IN and EV records

- WARNING: Inflows are not provided for control point \_\_\_\_\_. Zero flows are assumed.
- WARNING: CPIN repeats IN records from a CP that has no IN records.  
Control points CPID and CPIN are \_\_\_\_\_ and \_\_\_\_\_
- WARNING: For CP \_\_\_\_\_ INMETHOD= \_\_\_ on CP record but there are no IN records.



Table 7.5 SIM Warning Messages (Continued)

- 
- WARNING: CPEV repeats EV records from a CP that has no EV records.  
Control points CPID and CPEV are \_\_\_ and \_\_\_
- WARNING: Net evaporation-precipitation depths are not provided for control point \_\_\_\_  
Zero net evaporation-precipitation depths are assumed.
- WARNING: For CP \_\_\_ CPEV is blank on CP record but there are no EV records.

Written to MSS File from Subroutine RESCAL which computes reservoir evaporation and storage

- WARNING: End-of-month storage did not converge to within 0.1 acre-feet in 50 iterations of iterative evaporation computations for water right \_\_\_\_\_  
Reservoir: \_\_\_ CP: \_\_\_ Year: \_\_\_ Month: \_\_\_ Final Evap: \_\_\_  
BPSTOR: \_\_\_ EPSTOR: \_\_\_ 50th EPSTOR Adopted: \_\_\_

Written to MSS File from Subroutine RELEASE which computes multiple-reservoir system releases

- WARNING: Unable to deliver releases to water right \_\_\_ from reservoir \_\_\_ due to channel loss factor of 1.0

Written to MSS File from Subroutine POWER which performs hydropower computations

- WARNING: Energy produced did not converge to within 0.01 percent of target in 50 iterations of iterative hydropower computations for water right \_\_\_\_\_.  
Reservoir: \_\_\_ Year: \_\_\_ Month: \_\_\_ Energy target: \_\_\_  
BPSTOR: \_\_\_ 49th POWPRO \_\_\_ 50th POWPRO adopted: \_\_\_

Written to MSS File from Subroutines IACNP or FLDIST which read DIS file and distribute flows

- WARNING: The incremental CN and/or mean precipitation MP is negative for gaged \_\_\_ or ungaged \_\_\_  
gaged CN, ungaged CN, gaged MP, ungaged MP = \_\_\_\_\_
- WARNING: Convergence criterion of 0.5% was not met for flow distribution option 8 after 100 iterations at ungaged CP \_\_\_ for year \_\_\_, month \_\_\_\_\_. Last flow computed of \_\_\_ was adopted.
- WARNING: Evap-precip adjustment at control point \_\_\_ for EWA(cp) of \_\_\_ for year \_\_\_, month \_\_\_\_  
Runoff Adjustment (feet) = \_\_\_\_\_
- WARNING: The drainage area for CP \_\_\_ is missing, zero, or negative.
- WARNING: The CN of CP \_\_\_ violates the CN bounds: \_\_\_

Written to MSS File from Subroutine BISECT which solves CN equation for Subroutine FLDIST

- WARNING: Subroutine BISECT stopped at 100 iterations in solving the NRCS CN equation for P.
- 

### **Locating Errors in the SIM Output File**

With a completed simulation, *SIM* results organized with *TABLES* can be examined in great detail with the output data organized in a variety of tabulations. The *SIM* output SOU file provides an easy-to-read format but does not track the computational sequence as directly as the OUT file. If *SIM* terminates prior to completion, the OUT file still contains all results computed up to program termination. Essentially all numbers generated by *SIM* can be written to the OUT and scrutinized. The content and format of the records in the OUT file are outlined in Tables 5.1–5.5 of Chapter 5. The *SIM* simulation computations are outlined in Figure 2.2 in Chapter 2. Water right output records are written to the OUT file in sequence as each water right is considered in priority order. Control point and reservoir/hydropower output records are written to the OUT file for each month at the end of the water right priority loop.

The following discussion addresses the situation in which *TABLES* will not read an OUT file from an apparently successful execution of *SIM* even though the *TABLES* input file is completely correct. This situation should be encountered by model users seldom, if ever. After a *SIM* input dataset has been successfully debugged, irregularities in the *SIM* output OUT file should be rare.

Program *TABLES* includes a routine activated by the TEST record that performs a series of checks on a *SIM* output file. The TEST option in *TABLES* is designed for use in the unusual situation in which *TABLES* can not read an OUT file from a successful *SIM* simulation. The following tests are performed. The tests are applicable only to an OUT file created as a text file rather than as the optional unformatted binary file specified by *JD* record field 7.

*TABLES* reads the first record of the OUT file, and an error message is written to the TMS message file if irregularities are encountered. The problem will most likely be that *TABLES* is expecting a text file but the OUT file is not an ordinary text file. The only type of text file that can be read by *TABLES* is an ordinary text file with no enhancements. The Fortran code in *SIM* always creates a text file in the correct format. However, if the model-user reads the OUT text file with WordPad or some other editor and inadvertently saves the file in another format that adds formatting characters, *TABLES* will not be able to read the file. The TEST routine will detect the problem.

Most of the data in an OUT file are numbers. The TEST routine checks whether letters or other characters appear in the fields that should be numbers. Error messages are written to the TMS file if improper characters are found. The most likely problem is the occurrence of either *NaN* or *\*\*\*\*\** in the OUT file. The *SIM* code includes checks to prevent these situations from occurring. The *TABLES* TEST routine provides another backup check.

The term *NaN*, meaning *not a number*, is written by a Fortran program when an arithmetic operation is not defined. The undefined operation is usually dividing by zero. A number can not be divided by zero. The *SIM* code is written with checks to prevent divisions in which the denominator could be zero. However, if the safeguards fail, a *NaN* could be written to the OUT file and detected by the *TABLES* TEST routine.

Format specifications for the variables written to the OUT file are described in Chapter 5 of the *Reference Manual*. If a computed number has more digits than is allowed by a Fortran format statement, the number is replaced by the program with asterisks (*\*\*\*\*\**) in the output file. *SIM* includes safeguards to prevent this situation along with warning messages. However, the *TABLES* TEST routine will detect asterisks if they occur.

The TEST routine also checks that all water right output records in the OUT file are in the correct chronological order by year and month. For control point and reservoir output records, the control point and reservoir identifiers are read for the first month and checked for consistency in all subsequent months. Thus, an incorrect ordering of records or incorrect number of records will be detected. *SIM* should always write the correct number of records in the proper sequence. However, this test feature provides yet another check in exploring a corrupted file or occurrence of a strange unexplained problem.

### **Locating Errors in TABLES Input Data**

Instructions for applying the WRAP program *TABLES* are provided by Chapter 4 of the *Users Manual*. *TABLES* is very modular. Operations are controlled by records entered in an input file with filename extension TIN. *TABLES* reads one record of the TIN input file, performs the specified operations, records the results, and then proceeds to the next record in the TIN file. Trace messages are written to the message TMS file as each TIN file input record is read. Thus, if an input problem occurs, the input record causing the problem is evident.

All of the WRAP programs have the same basic system for recording error and warning messages on the monitor and in the message file. *TABLES* is the same as *SIM* and *HYD* in this regard. Checks are embedded in various routines in *TABLES*. Program execution is terminated with error messages but is not terminated with warning messages.

### **Locating Errors in HYD Input Data**

*WRAP-HYD* contains features similar to those of *WRAP-SIM* to help detect missing records or inconsistencies and locate erroneous records that cause program execution to terminate due to illegal computer operations. These features do not pertain to those situations in which reasonable but incorrect data are input in the right format.

#### **Tracking Program Progress**

Tracing the progress of reading input records and performing computations up to program termination may be useful in locating the input record causing the problem. The following *HYD* features trace the progress of the simulation.

*HYD* execution begins with an interactive session in which the user supplies the root of the input and output filenames, and the files are opened. The program checks whether the specified files exist, writes a message to the monitor if an input file is missing, and allows the user to confirm overwriting of existing output files. The messages shown in Table 7.6 then appear on the monitor as various tasks are performed.

Progress is tracked in more detail by notes the program writes to the message file, which has the filename extension HMS. If program execution is terminated prior to completion the specified tasks, the trace messages help locate the input record causing the problem. Optional levels of input data traces are specified by input variable *ICHECK* in field 4 of the *JC* record. The basic trace (*ICHECK*  $\geq$  0) consists of printing the messages shown in Table 7.7 to the HMS file. Only those messages associated with options included in the *HYD* application will be written to the message file. If model execution is prematurely terminated, the last message provides the approximate location in the input files at which a problem occurred.

Additional information noted in Table 7.7 may also be written to the message file as specified by *ICHECK* in field 4 of the *JC* record. The *ICHECK* = 1 trace shown in Table 7.7 is used to find the general location of the problem record based on where the trace stops. The program is then rerun with a different *ICHECK* value to check which records in the groups noted in Table 7.7 are read and copied correctly.

Table 7.6  
HYD Trace Displayed on Monitor

---

```

Reading the input data from file_____.HIN
*****
HIN file record counts:
  ___ control points
  ___ control points with IN records
  ___ OUT input file OI records
  ___ evap-precip rate adjustment EP records
  ___ representative year AN records
  ___ adjustment specification AS records
  ___ adjustment equation EQ records
*****
Reading the IN/EV records
Developing EV records as specified by EP records
Adjusting flows as specified by AS records
Distributing flows from gaged to ungaged control points (FD records)
Writing IN and/or EV records to output file(s)

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

```

---

ICHECK options 3 through 7 should seldom if ever be required, but provide a backup approach for otherwise hard-to-find input errors. For *ICHECK* options 3 through 7, the records noted in Table 7.7 are written to the HMS file immediately after each record is read. The records are copied to the HMS file almost verbatim as read, except most real numbers are written in a F8.0 Fortran format with zero digits to the right of the decimal point. Blank fields read as zeros are output as zeros. If the program reads some but not all records of a particular record type, the problem will typically be associated with either the last record read and copied to the HMS file or more likely the next record in the input file.

Table 7.7  
Trace Information Copied to Message File for Various Values of ICHECK

---

ICHECK = 0	Messages shown in Table 7.8; most error detection routines in effect
ICHECK = 1	Messages shown in Table 7.8; all error detection routines in effect
ICHECK = 2	Messages shown in Table 7.8; IN and EV record check
ICHECK = 3	Messages shown in Table 7.8 plus all <i>CP</i> records as read
ICHECK = 4	Messages shown in Table 7.8 plus all <i>AS</i> records as read
ICHECK = 5	Messages shown in Table 7.8 plus all <i>SV</i> and <i>SA</i> records as read
ICHECK = 6	Messages shown in Table 7.8 plus all <i>IN</i> and <i>EV</i> records as read
ICHECK = 7	Messages shown in Table 7.8 plus all <i>FD</i> , <i>FC</i> , and <i>WP</i> records as read

---

Table 7.8  
HYD Trace Messages Written to HMS File

---

```

*** Starting to read file _____.HIN.
*** JC record was read.
*** Starting to read CP records.
*** Finished reading CP records.
*** Starting to read CI records.
*** Finished reading CI records.
*** Starting to read SV/SA records.
*** Finished reading SV/SA records.
*** Counting EP records. (They will be reread later.)
*** Finished reading file _____.HIN.
*****
Number of CP, SV/SA, and EP records read from HIN file.
    ____ control point CP records
    ____ control points with IN records
    ____ storage-area table SV/SA records
    ____ evap-precip rate adjustment EP records
*****
*** Starting ICHECK=2 check of IN records.
*** Finished ICHECK=2 check of ____ IN records.
*** Starting ICHECK=2 check of EV records.
*** Finished ICHECK=2 check of ____ EV records.
*** Starting to read IN/EV records.
*** Rearranging first year inflows and multiplying by factors on CP records.
*** Reading first year evap-precip rates.
*** Rearranging first year evap and multiplying by factors on CP records.
*** Finished reading IN/EV records.
*** Starting to read IN records from INF file in optional format [JC(1)=2].
*** Reordering IN records and multiplying by factors on CP records.
*** Starting to read EV records from EVA file in optional format [JC(1)=2].
*** Reordering EV records and multiplying by factors on CP records.
*** Finished reading IN/EV records.
*** Starting to read EP records.
*** Finished developing EV records as specified by EP records.
*** Starting to adjust flows as specified by AS and/or EQ records.
*** Finished adjusting flows as specified by AS and/or EQ records.
*** Starting negative incremental flow routine (ADJINC/NEGINC on JC record).
*** Finished negative incremental flow routine.
*** Starting to read flow distribution DIS file.
*** Finished reading flow distribution DIS file.
*** Starting flow distribution computations.
*** Finished flow distribution computations.
*** Starting to write IN and/or EV records to FLO/EVA files.

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

```

---

### ICHECK Option 2 IN and EV Record Checks

SIM and HYD performed similar checks when reading inflow *IN* and evaporation *EV* records with ICHECK option 1 selected in *JD* or *JC* record field 4. ICHECK option 2 in *HYD* activates a routine that performs a series of checks of *IN* and *EV* records that includes several extra checks in addition to those performed with ICHECK option 1. The *HYD* ICHECK option 2 checks are performed on INF and EVA files that may serve as input files for either *HYD* or *SIM*. The *ICHECK=2* routine is applicable to INF and EVA files but not a *HYD* file. Checks performed for ICHECK option 2 result in the normal error messages for Fortran IOSTAT errors and result in warning messages written to the HMS file if the following irregularities are detected.

- Control point identifiers on *IN* and *EV* records must match identifiers on *CP* records.
- *IN* records should correspond to INMETHOD(cp) option 1 on the *CP* records.
- *EV* records should correspond to a blank CPEV(cp) on the *CP* records.
- Years on *IN* and *EV* records should fall within the period-of-analysis defined by JC(1) and JC(2).
- Years on *IN* and *EV* records should increase sequentially in chronological order.
- The number of *IN* and *EV* records should be consistent for each year and each control point. The total numbers of *IN* and *EV* records are recorded.

The routine reads the control point identifiers entered in field 2 of the *IN* and *EV* records and matches them against those on the *CP* records. The following warning message is written to the HMS file for each *IN* or *EV* record that does not match a *CP* record.

WARNING: Control point \_\_\_ on (IN or EV) record matches no identifier on CP records.

If *IN* records are provided, the variable *INMETHOD* in field 6 of the *CP* record should be zero or one. If this is not the case, the following message is written.

WARNING: INMETHOD is \_\_\_ on CP record for control point \_\_\_\_\_ on IN record.

If *EV* records are provided, field 8 of the *CP* record (*CPEV*) should be blank. If this is not the case, the following message is written.

WARNING: CPEV is \_\_\_\_\_ on CP record for control point \_\_\_\_\_ on EV record.

Similar warning messages are activated by other ICHECK=2 checks.

### Error and Warning Messages

*HYD* contains a variety of other error and warning checks that are applied with the other ICHECK options in addition to the ICHECK option 2 checks noted above. Most are performed as the input files are read. If data are missing or in the wrong format, program execution is stopped and an error message is written. Warning messages identify potential problems, but program execution is not terminated. Error and warning messages are written to the HMS file. *HYD* and *SIM* both generate two types of error messages:

1. The Fortran input/output status specifier *IOSTAT* is included in most of the read statements.
2. Many other specific error check algorithms are coded into the various routines. Many of the *SIM* error messages and other similar messages are incorporated in *HYD*.

If violation of a Fortran rule is indicated by the *IOSTAT* variable in a read statement, the following complete message is written to the message file, the first two lines of the message are displayed on the monitor, and execution is terminated.

ERROR: Fortran IOSTAT error occurred reading an input record with identifier CD of \_\_\_\_  
 IOSTAT status variable = \_\_\_\_  
 The first 80 characters of each of the last two records read are as follows:

The last two records read from the input file prior to termination of the program are written following this message. The message indicates the value for the *IOSTAT* variable as defined within the Fortran language compiler. A negative one (-1) means the end of file was reached without finding the data record. A -2 indicates the end of the record was reached without finding the data. A positive integer refers to error condition messages provided by the compiler. The most common value for the *IOSTAT* variable is 64, which means input data is in the wrong format, such as a letter in a real or integer numeric field or a decimal in an integer field. A 39 indicates a problem with a read statement, but no information regarding the problem is available.

Other *HYD* warning and error messages are listed in Tables 7.9 and 7.10. Subroutines *INFEV1*, *INEV2*, *INEVYR*, *IACNP*, *FLDIST*, and *BISECT* are essentially the same in *HYD* and *SIM* and have the same error and warning messages. The *SIM* messages identified with these shared subroutines in Tables 7.4 and 7.5 are not repeated in Tables 7.9 and 7.10, which show many of the additional *HYD* messages that are not in *SIM*.

Table 7.9  
 HYD Warning Messages

---

WARNING: ICHECK=2 option specified on JC record is invalid without FLO and EVA files.  
 WARNING: No output is written since INEV(1)=5 in field 12 of first CP record.  
 WARNING: No input is specified on JC record.  
 WARNING: No output file is specified in JC record.  
 WARNING: First year in OUT file does not match YRST on JC record: \_\_\_\_ \_\_\_\_  
 WARNING: Number of years in OUT file does not match NYRS on JC record: \_\_\_\_ \_\_\_\_  
 WARNING: Control point identifier \_\_\_\_ in OUT file matches no CP record in HIN file.  
 WARNING: Control point identifier \_\_\_\_ on CP record is not found in OUT file.  
 WARNING: Reservoir identifier \_\_\_\_ in OUT file matches no reservoir in HIN file though JC(2)=7.)  
 WARNING: Reservoir identifier \_\_\_\_ on CP record is not found on reservoir records in OUT file though JC(2)=7.  
 WARNING: Inflows are not provided for control point \_\_\_\_ . Zero flows are assumed.  
 WARNING: Net evaporation-precipitation depths are not provided for control point \_\_\_\_ zero net  
 evaporation-precipitation depths are assumed.  
 WARNING: Read a FA record when Abs(AS(3)) is greater than 1.  
 WARNING: Read a RS record when AS(3) is not 2.

---

Table 7.10  
HYD Error Messages

---

Written to HMS File from Subroutine READHIN

ERROR: Missing JC record.  
ERROR: Number of years on JC record must be at least one.  
ERROR: JC(1,2,3,4,5,6) of \_\_\_ on JC record is not valid.  
ERROR: ADJINC of \_\_\_ and NEGINC of \_\_\_ on JC record are not compatible.  
ERROR: ADJINC of \_\_\_ on JC record is not valid.  
ERROR: EPDADJ of \_\_\_ in JC field 13 is not valid.  
ERROR: Control point \_\_\_ has an invalid INEV of \_\_\_ (CP record field 12)  
ERROR: Following CP record for control point \_\_\_ a record with CD of \_\_\_ was read instead of MF.  
ERROR: Missing CP record. Read CD of \_\_\_  
ERROR: Control point \_\_\_ has an invalid INMETHOD of \_\_\_  
ERROR: Downstream control point identifier [CPID(cp,2)] \_\_\_ on CP record for \_\_\_ matches no CPID(cp,1).  
ERROR: Identifier \_\_\_ is assigned to both control points \_\_\_ and \_\_\_  
ERROR: (CPIN(cp),CPEV(cp)) of \_\_\_ on CP record for control point \_\_\_ matches no CPID(cp,1) identifier.  
ERROR: Control point identifier \_\_\_ from CI record \_\_\_ matches no control point identifier on CP records.  
ERROR: Missing SV/SA record. Read CD of \_\_\_  
ERROR: Missing or duplicate reservoir ID found while reading SV/SA records.  
ERROR: VAR of \_\_\_ on OI record is not valid.  
ERROR: OG of \_\_\_ on OI record is not valid.  
ERROR: OID of \_\_\_ on OI record is on no CP record.  
ERROR: Read CD of \_\_\_ instead of supplemental AN record.'  
ERROR: \_\_\_ in AN record field (3,4,6) is not valid.  
ERROR: ID of \_\_\_ on AN record is not on any CP record.  
ERROR: Year in AN field 9 of \_\_\_ is less than JC field 2 YRST of \_\_\_  
ERROR: Year \_\_\_ in AN record field 10 exceeds NYRS on JC record.  
ERROR: CP identifier of \_\_\_ from EP record matches no identifier on the CP records.  
ERROR: Read CD of \_\_\_ which is not valid for HIN file.

Written to HMS File from Subroutine EPADD

ERROR: ID of \_\_\_ from EP record matches no identifier on the CP records.  
ERROR: Read CD of \_\_\_ when expecting an EP record.

Written to HMS File from Subroutine FLOWADJ

ERROR: JC(3) of \_\_\_ on JC record is not valid.  
ERROR: AS(3,4,5) of \_\_\_ on AS record is not valid.  
ERROR: ID of \_\_\_ on AS record matches no identifier on the CP records.  
ERROR: CD of \_\_\_ found when expecting (FA,SC) record.  
ERROR: In reading (FA,SC) record for CP \_\_\_\_, read year of \_\_\_ when expecting \_\_\_\_  
ERROR: RS(1,2,3,4,5,6) of \_\_\_ on RS record is not valid.  
ERROR: The identifier \_\_\_ on RS record matches no reservoir identifier on SV records.  
ERROR: Interpolation of SV/SA records is out of range for reservoir \_\_\_\_  
ERROR: In performing flow adjustments, reached end of input file (unit=\_\_\_) without reading ED record.

---

### **HEC-DSS Trace Messages**

The Hydrologic Engineering Center (HEC) Data Storage System (DSS) is described in the preceding Chapters 1 and 6. Routines from a HEC-DSS library are incorporated into the Fortran code of *SIM*, *TABLES*, and *HYD* allowing creation of and access to DSS files. *WRAP-*



*SIM* and *WRAP-HYD* contain options to create DSS files and both read and write data to DSS files. *TABLES* includes routines to create a DSS file and write data to the DSS file.

The HEC-DSS library routines distributed by the Hydrologic Engineering Center include trace messages that are written to the message file. The message files in *SIM*, *TABLES*, and *HYD* have filename extensions MSS, TMS, and HMS, respectively. The DSS messages are written to the MSS, TMS, and HMS files along with the other messages generated by *SIM*, *TABLES*, and *HYD*. However, the DSS messages are in the DSS format controlled by the HEC-DSS library routines.

*SIM* parameters relating to DSS files are contained in *OF* record fields 4, 5, 6, 7 and in *JO* record field 2. *TABLES* parameters dealing with DSS files are entered on the FILE record, type 2 time series records, and 4ZZZ records described in the *Users Manual* and other records related to organizing *SIMD* and *SALT* output covered in the *Supplemental Manual*. *HYD* parameters controlling DSS files are entered on *JC* record fields 5, 6, 12, 13, 19, and 20.

The HEC-DSS routines create a variety of different types of messages. A DSS parameter sets the level of messages to be written to the message file. For *SIM*, this optional parameter is entered as DSS(6) in *OF* record field 7. The parameter controlling the DSS message level is entered on the *TABLES* FILE record and in *HYD JC* record field 19. Each of the DSS message levels defined in Table 7.11 includes all of the messages from preceding lower levels plus additional messages.

Table 7.11  
DSS Message Levels

Level	Type of Message
-1	Only messages indicating program has aborted due to some problem.
1	Statements indicating that a DSS file has been opened or closed.
2 (default)	Error and warning messages if DSS problems are encountered.
3	Trace of all DSS records written to DSS files.
4	Trace of all DSS records read from DSS files.
5	Not used.
6	Not Used.
7	Beginning level of debugging messages.
8	Intermediate level of debugging messages.
9	Maximum level of debugging messages.

Level 2 is activated by default unless another option is selected. Levels 3 and 4 include listing of records by pathname as they are read from or written to a DSS file as well as the messages also activated at the lower levels. Levels 7, 8, and 9 provide debugging messages for the DSS subroutines of interest to programmers which hopefully WRAP users will never see nor need.

## REFERENCES

- Center for Research in Water Resources, University of Texas at Austin, *WRAP Display Tool, Users Manual and Operating Instructions*, Prepared for the Texas Commission on Environmental Quality, Austin, Texas, December 2007.
- Dunn, David D., *Incorporation of System Operation Strategies in Water Rights Modeling and Analysis*, Master of Science Thesis, Texas A&M University, August 1993.
- Figurski, Melissa J., and David R. Maidment, *GIS Algorithms for Large Watersheds with Non-contributing Areas*, Center for Research in Water Resources, University of Texas at Austin, Online Report 01-7, December 2001. <http://www.crrw.utexas.edu/online.shtml>
- Gopalan, Hema, *WRAP Hydro Data Model: Finding Input Parameters for the Water Rights Analysis Package*, Texas Water Resources Institute, Technical Report 233, Center for Research in Water Resources, University of Texas at Austin, Online Report 03-3, May 2003.
- Hudgens, Bradley T., and David R. Maidment, *Geospatial Data in Water Availability Modeling*, Center for Research in Water Resources, University of Texas at Austin, Online Report 99-4, December 1999. <http://www.crrw.utexas.edu/online.shtml>
- Hydrologic Engineering Center, *HECDSS Users Guide and Utility Programs Manuals*, U.S. Army Corps of Engineers, Davis, CA, March 1995.
- Hydrologic Engineering Center, *HECDSS Microsoft Excel Data Exchange Add-In*, U.S. Army Corps of Engineers, Davis, CA, November 2003.
- Hydrologic Engineering Center, *HEC-DSSVue HEC Data Storage System Visual Utility Engine, User's Manual*, Version 1.2, U.S. Army Corps of Engineers, Davis, CA, May 2005.
- Maidment, David R. (Editor), *Arc Hydro GIS for Water Resources*, ESRI Press, 2002.
- Mason, David, and David R. Maidment, *An Analysis Methodology for Generating Watershed Parameters Using GIS*, Center for Research in Water Resources, University of Texas at Austin, Online Report 00-3, May 2000. <http://www.crrw.utexas.edu/online.shtml>
- Olmos Alejo, Hector E., *Improving Capabilities for Dealing with Key Complexities of Water Availability Modeling*, M.S. Thesis, Texas A&M University, December 2004.
- Sanchez-Torres, Gerardo, *Reservoir System Reliability Considering Water Rights and Water Quality*, Ph.D. Dissertation, Texas A&M University, December 1994.
- Salazar, A. Andres, *Conditional Reliability Modeling to Support Short Term River Basin Management Decisions*, Ph.D. Dissertation, Texas A&M University, May 2002.
- Sokulsky, Kariann, Tina Dacus, Lann Bookout, and Jim Patek, "Water Availability Modeling Project: Year 1 - Concept Plan, Overview of the New Modeling System and Its Role in Regional Planning," *Proceedings of the 25<sup>th</sup> Water for Texas Conference, Water Planning Strategies for Senate Bill 1* (Edited by R. Jensen), Texas Water Resources Institute, Dec. 1998.
- Texas Natural Resource Conservation Commission, *Water Availability Modeling: An Overview*, GI-245, July 1998.
- Walls, W. Brian, *Application of a Water Rights Analysis Program to Reservoir System Yield Calculations*, Master of Science Thesis, Texas A&M University, August 1988.
- Wurbs, R.A., C.E. Bergman, P.E. Carriere, P.E., and W.B. Walls, *Hydrologic and Institutional Water Availability in the Brazos River Basin*, Technical Report 144, Texas Water Resources Institute, August 1988.

- Wurbs, R.A., and W.B. Walls, "Water Rights Modeling and Analysis," *Journal of Water Resources Planning and Management*, American Society of Civil Engineers, Vol. 115, No. 4, July 1989.
- Wurbs, R.A., G. Sanchez-Torres, and D.D. Dunn, *Reservoir/River System Reliability Considering Water Rights and Water Quality*, TR-165, Texas Water Resources Institute, March 1994.
- Wurbs, R.A. and A.K. Yerramreddy, "Reservoir/River System Analysis Models: Conventional Simulation versus Network Flow Programming," *International Journal of Water Resources Development*, Carfax Publishing, Vol. 10, No. 2, 1994.
- Wurbs, R.A., and D.D. Dunn, *Water Rights Analysis Package (TAMUWRAP), Model Description and Users Manual*, TR-146, TWRI, March 1993, revised October 1996.
- Wurbs, R.A., and E.D. Sisson, *Evaluation of Methods for Distributing Naturalized Streamflows from Gaged Watersheds to Ungaged Subwatersheds*, TR-179, TWRI, August 1999.
- Wurbs, R.A., *Water Rights Analysis Package (WRAP), Model Description and Users Manual*, Technical Report 180, Texas Water Resources Institute, First Edition August 1999, Second Edition October 2000, Third Edition July 2001.
- Wurbs, R.A., "Assessing Water Availability under a Water Rights Priority System," *Journal of Water Resources Planning and Management*, American Society of Civil Engineers, Vol. 127, No. 4, July/August 2001.
- Wurbs, R.A., "Water Allocation Systems in Texas," *International Journal of Water Resources Development*, Carfax Publishing, Vol. 20, No. 2, June 2004.
- Wurbs, R.A., "Natural Salt Pollution Control in the Southwest," *Journal of the American Water Works Association*, Vol. 94, No. 12, December 2002.
- Wurbs, R.A., "Modeling River/Reservoir System Management, Water Allocation, and Supply Reliability," *Journal of Hydrology*, Elsevier Science Publishers, Vol. 300, 2005.
- 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/August 2005.
- Wurbs, R.A., R.S. Muttiah, F. Felden, "Incorporation of Climate Change in Water Availability Modeling," *Journal of Hydrologic Engineering*, American Society of Civil Engineers, Vol. 131, No. 5, September/October 2005.
- Wurbs, R.A., "Methods for Developing Naturalized Monthly Flows at Gaged and Ungaged Sites," *Journal of Hydrologic Engineering*, American Society of Civil Engineers, Vol. 11, No. 1, January/February 2006.
- 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 Modeling System Users Manual*, Technical Report 256, Texas Water Resources Institute, Fourth Edition, March 2008.
- Wurbs, R.A., *Fundamentals of Water Availability Modeling with WRAP*, Technical Report 283, Texas Water Resources Institute, Fourth Edition, March 2008.
- Wurbs, R.A., R.J. Hoffpauir, H.E. Olmos, and A.A. Salazar, *Conditional Reliability, Sub-Monthly Time Step, Flood Control, and Salinity Features of WRAP*, Technical Report 284, Texas Water Resources Institute, September 2006.
- Yerramreddy, Anil R., *Comparative Evaluation of Network Flow Programming and Conventional Reservoir System Simulation Models*, M.S. Thesis, Texas A&M University, August 1993.

## APPENDIX A GLOSSARY

Each of the terms included in this glossary is defined and discussed in more detail in various parts of the manual. Terms are defined specifically from the perspective of their use in this manual.

**active pool** – reservoir storage zone from which releases and withdrawals are made.

**adjusted net evaporation-precipitation** – *JD* record field 10 and *CP* record field 9 activates a *SIM* option to account for the portion of the reservoir water surface evaporation-precipitation that is also reflected in the naturalized streamflow inflows. The ratio of reservoir surface area to watershed area is used to determine the proportion of the naturalized streamflow that is runoff from the land now covered by the reservoir. The net evaporation-precipitation rate is adjusted to prevent double-counting this inflow.

**available streamflow** – The streamflow available to a water right is computed by *SIM* as an initial step as each right is considered in the water rights priority loop which is embedded within the monthly loop.

**backup right** – A backup water right activated by a *BU* record adds any shortage incurred by the other right being backed-up to its own target. Thus, multiple rights may be assigned to meet a particular target. The secondary backup right supplies the target only to the extent that the other right can not due to insufficient water availability.

**channel loss credits** – Credits represent increases in streamflow to result from incorporating channel losses in *SIM*. For example, diversions reduce streamflows at downstream control points less if channel losses are considered.

**channel loss factor** – The channel loss factor *CL* entered on the *CP* record is used to determine channel losses in the river reach below a control point as follows where  $Q_{upstream}$  is the flow at the control point:  $channel\ loss = CL\ Q_{upstream}$

**channel losses** – Channel losses represent the portion of the streamflow in the reach between two control points that is loss through infiltration, evapotranspiration, and diversions not reflected in the water rights. Channel loss *L* is treated as a linear function of the flow  $Q_{upstream}$  at the control point defining the upstream end of the reach [ $L = CL\ Q_{upstream}$ ] where *CL* is a channel loss coefficient provided as *HYD* or *SIM* input.

**conditional reliability modeling** – An optional modeling approach activated by *SIM CR* record and *TABLES* type 5 records analyzes water supply reliabilities and flow and storage frequencies over relatively short periods of a month to a year conditioned upon specified preceding reservoir storage conditions.

**constant inflow or outflow** – An option allows a set of 12 flows for the 12 months of the year entered on *CI* records to be either added or subtracted from streamflow each year. This flows may represent intrabasin or interbasin water transport, return flows from groundwater sources, losses or other flows not otherwise reflected in the water rights input.

**control point** – Control points are stations or nodes which provide a modeling mechanism for representing the spatial connectivity of system components. The locations of system features are defined by control points. The spatial configuration of the system is delineated by specifying the control point located immediately downstream of each control point.

- curve number method adaptation** – This method of distributing flows described in Chapter 3 is based on a modified version of the Natural Resource Conservation Service (NRCS) rainfall-runoff modeling methodology which uses the curve number *CN* to represent the land cover and soil types of the watersheds.
- delivery factor** – In considering channel losses, the delivery factor is one minus the channel loss factor ( $DF = 1 - CL$ ) and represents the fraction of the flow at the upstream control point that reaches the next downstream control point.
- diversion** – Computed by *SIM* as a diversion target limited by water availability. The water supply diversion requirement minus the computed diversion is the computed shortage.
- drainage area ratio method** – Naturalized flows at an ungaged site are estimated from flows at a gaged location based on proportioning the flows in proportion to the drainage areas of the gaged and ungaged watersheds.  $Q_{ungaged} = R_{DA} Q_{gaged}$  where  $R_{DA}$  is the drainage area ratio
- drought index** – A drought or storage index (*DI/IP/IS* records) allows diversion, instream flow, and hydropower requirements to be specified as a function of the storage content of specified reservoirs. The drought index is expressed in the format of a table of storage content versus a percentage multiplier which is applied to the target diversion, instream flow, or hydropower amount associated with a water right.
- DSS file** – WRAP programs create, read, and write to DSS files in the direct access binary format of the Data Storage System (DSS) developed by the USACE Hydrologic Engineering Center.
- dual simulation option** – An automated dual simulation activated by the *JO*, *SO* or *PX* record allows streamflow depletions during a first simulation with specified water rights to serve as a limit on streamflow depletions during a second simulation with modified water rights.
- energy requirement** – An annual hydroelectric energy target in units of megawatt hours per year or similar units is entered in *WR* record field 3. *SIM* determines a monthly energy target by combining the annual target with monthly distribution factors (*UC* records) and other optional target setting records. An energy target is determined the same as a diversion target.
- evaporation** – Evaporation from the water surface of reservoirs is included in the volume accounting computations by combining depths from *EV* records with water surface areas determined as a function of storage volume. The evaporation in WRAP is actually a net evaporation minus precipitation depth or volume.
- evaporation-precipitation** – Net evaporation minus precipitation depth or volume. Evaporation represents a loss of water from the reservoir. Conversely, precipitation is a gain.
- evaporation-precipitation rate** – Monthly rates expressed as depths of evaporation minus precipitation are provided as model input in inches, feet, or other units of depth per month.
- evaporation-precipitation volume** – In the water volume accounting computations, the monthly net evaporation-precipitation volume is determined as the rate (depth/month) multiplied by the average surface area of the reservoir for the month.
- exceedance frequency** – The percentage of the total months in the overall simulation period-of-analysis that a particular amount is equaled or exceeded. *TABLES* develops exceedance frequency relationships for naturalized, regulated, and unappropriated streamflow, instream flow shortage, reservoir storage, and reservoir water surface elevation.

**firm yield** – The maximum water supply diversion or hydropower electric energy generation that can be achieved with a volume and period reliability of one-hundred percent (to a defined level of precision) based on the premises reflected in the model. The *SIM* firm yield *FY* record activates an automated iterative search for the firm yield.

**flow distribution methods** – Several alternative methods are described in Chapter 3 for synthesizing naturalized streamflows at ungaged (unknown flow) control points based on known flows at other control points read from *IN* records and watershed parameters from a flow distribution *DIS* file.

**flow distribution equation** –  $Q_{\text{ungaged}} = a (Q_{\text{gaged}})^b + c$  with coefficients *a*, *b*, and *c* input on *FC* records is one of several flow distribution methods. With default values of one and zero for *b* and *c* and the drainage area ratio used for the coefficient *a*, the equation reduces to the drainage area ratio method.

**Fundamentals Manual** – TWRI Technical Report 283 entitled *Fundamentals of Water Availability Modeling with WRAP* provides an introductory overview of WRAP.

**head** – The vertical water surface elevation difference between upstream and downstream of the turbines used in the power equation (Equation 4-4). *SIM* computes head as a reservoir water surface elevation minus tailwater elevation.

**HEC-DSS** – The Hydrologic Engineering Center (HEC) Data Storage System (DSS) developed by the HEC of the U.S. Army Corps of Engineers is a database management system used with both HEC and non-HEC simulation models including WRAP.

**HEC-DSSVue** – The USACE Hydrologic Engineering Center HEC-DSS Visual Utility Engine is a user-friendly software package for managing, plotting, and manipulating data in DSS files. WRAP programs write simulation results to DSS files for transport to HEC-DSSVue.

**HYD** – see WRAP-HYD

**hydrologic simulation period** – In a *WRAP* simulation, specified annual water use requirements, distributed over the 12 months of the year, are met, subject to water availability, during a hypothetical repetition of historical hydrology represented by sequences of naturalized streamflows and net evaporation-precipitation rates for each month of a multiple-year hydrologic simulation period, which is also called the period-of-analysis.

**inactive pool** – The bottom pool of a reservoir from which releases or withdrawals cannot be made except by evaporation. The inactive pool storage capacity is entered in *WS* record field 7.

**incremental streamflows** – An incremental flow is the difference between total flows at adjacent control points. *WRAP* computational algorithms, as well as input and output data, are based on total flows rather than incremental inflows. However, *HYD* and *SIM* include options for checking for negative incremental naturalized streamflows and adjusting the flows to remove the negative incrementals. Incremental flow options are controlled by *JD* record fields 8 and 9.

**inflows to a control point** – This quantity referenced in *TO* record fields 5 and 6 and *FS* record field 2 and tabulated by the *2CPI* record represents inflows into a control point excluding releases from secondary reservoirs located upstream for water rights located downstream of the control point. The inflow is computed as the regulated flow plus streamflow depletion at the control point minus secondary reservoir releases.

**instream flow requirement** – A water right requirement entered on an *IF* record consists of placing a minimum target limit on the regulated flows at a control point. The objective is to maintain regulated streamflows at or greater than the target if feasible.

**junior right** – see senior or junior rights

**lakeside versus downstream water supply release** – *WS* record field 11 allows specification of whether or not water supply diversions are used to generate energy for more junior hydropower rights. By default, diversions for senior water rights are allowed to pass through the turbines to generate power for junior hydropower rights. However, the lakeside diversion option activated by *WS* record field 11 for a diversion right results in the diversion bypassing the turbines and not contributing to power generation.

**multiple-reservoir system operations** – A single water right diversion, instream flow, or hydroelectric power target may be met by releases from multiple reservoirs following rules specified on *OR* records. Multiple-reservoir release rules are based upon balancing the storage content expressed as a percentage of capacity in specified vertical active pool zones of each system reservoir.

**natural priority option** – Water right priorities are ordered internally within *SIM* in upstream to downstream order if the natural priority option is specified in the *JO* record. This ranked order is used in lieu of the water right priorities entered on *WR* records.

**naturalized streamflows** – Sequences of monthly streamflows representing natural hydrology are developed by adjusting historical gaged streamflow data to remove the impacts of reservoir construction, water use, and other human activities. Naturalized streamflows are provided as *SIM* input data on inflow *IN* records.

**period reliability** – The reliability index reflected in Equation 5.2 is the percentage of the total months or years (periods) in the overall simulation period-of-analysis that a specified percentage of a diversion target or hydroelectric energy target is met.

**permitted, authorized, or target diversion** – The diversion requirement or target amount of water to be appropriated from streamflow at a control point location and reservoir storage at the same or other locations.

**permitted, authorized, or target energy requirement** – Hydroelectric energy generation target.

**precipitation** – Precipitation falling directly on the water surface of reservoirs is included in the reservoir volume accounting computations through the net evaporation-precipitation depth.

**primary and secondary control points** – Naturalized streamflows are input to *SIM* on *IN* records for primary (known-flow or gaged) control points. Secondary control points are locations for which naturalized streamflows are computed in *SIM* from flows at one or more primary control points and watershed parameters used methods outlined in Chapter 3.

**primary and secondary reservoirs** – The terms primary reservoir and secondary reservoir are defined in the context of water rights. Primary reservoirs are refilled by the water right in question; secondary reservoirs are not refilled. Any number of reservoirs can be associated with each water right. However, storage capacity can be refilled in only one primary reservoir. The other secondary reservoirs make releases to meet diversion, instream flow, or hydropower requirements but cannot be refilled by the water right. A secondary reservoir for one water right can be a primary reservoir for another water right and vice versa.

**priority** – An integer value associated with a water right indicating the seniority of the right relative to all the other rights. In each period of the simulation, water rights are considered in turn and available water appropriated in order of their relative priorities. Priorities are entered on the *WR* and *IF* records and may be adjusted by options on the *UP* records or replaced by the natural priority option activated with the *JO* record.

**priority circumvention options** – The *PX* record controls four different modeling features designed to deal with water management situations in which the normal priority system is not applicable. Water management actions evade the priority sequence in the model.

**Reference Manual** – WRAP is documented by this *Reference Manual* and the *Users Manual*, *Fundamentals Manual*, and *Supplemental Manual*.

**regulated streamflows** –*SIM* computed regulated flows, associated with a particular control point, represent the physical streamflow after accounting for all the water rights. The *SIM* simulation starts with naturalized flows and computes regulated flows. Regulated flows may be greater than unappropriated flows because a portion of the regulated flows may be committed to meet instream flow requirements or downstream diversion or storage rights.

**record** – Data is recorded in input and output files as records. A record is one line of data in a text file or a time series referenced by a pathname in a DSS file. Input records are described in the *Users Manual*. Output records are described in Chapter 5 of this *Reference Manual*.

**return flow** – An amount of water computed as the diversion multiplied by an inputted return flow factor is returned to the stream system at a user-specified control point in either the same month as the diversion or the next month as specified by the *WR* record. Return flows may also be modeled as constant inflows entered on *CI* records.

**run-of-river water right** – A water right with zero reservoir storage capacity.

**SALT** – see WRAP-SALT

**seasonal rule curve operations** – A model option activated by the *MS* record allows the storage capacity of a reservoir to vary monthly over the 12 months of the year. The primary application of this option is modeling reservoirs with operating plans based on seasonal allocations of storage capacity between flood control and conservation pools.

**secondary control points** – See primary and secondary control points.

**secondary energy** – Additional hydroelectric energy, above the permitted energy target, which could be generated incidentally by pass-through flows and releases for more senior water right diversions.

**secondary reservoirs** – See primary and secondary reservoirs.

**senior or junior rights** – A water right is senior or junior relative to another water right depending on the priority number included in the input data for each right. A senior right has the highest priority, which is represented by the smallest priority number (earliest date or other priority indicator) and is considered first in the water allocation computations.

**shortage** – Diversion target minus actual diversion or energy target minus actual energy produced. A shortage is the amount of a diversion or energy target not supplied due to insufficient streamflow and/or reservoir storage being available to meet the full target.



**storage-area relationship** – A relationship between reservoir storage volume and water surface area is required in the computation of net evaporation-precipitation volumes. This relationship may be input alternatively as a storage versus area table (*SV/SA* records) or as coefficients for an equation (*WS* record fields 4, 5, 6).

**storage-elevation relationship** – A relationship between reservoir storage volume and water surface elevation is required in the computation of head in the hydropower routine. This relationship is input as a storage volume versus elevation table (*PV/PE* records).

**streamflow depletion limit** – Limits may be placed on the amount of streamflow a right can appropriate in a year, season, or month of the year to meet streamflow and storage targets using options on the *SO* record.

**streamflow depletion** –*SIM* computed streamflow depletions are the amounts appropriated to meet water right diversions, account for reservoir net evaporation-precipitation, and/or refill reservoir storage. Each streamflow depletion is associated with a particular right.

**Supplemental Manual** – TWRI Technical Report 254 entitled *Conditional Reliability, Sub-Monthly Time Step, Flood Control, and Salinity Features of WRAP* documents these features which are not covered in the basic *Reference* and *Users Manuals*.

**TABLES** – This post-simulation program develops tables, data listings, and reliability indices from *SIM* input and output files that organize/summarize the simulation results.

**tailwater** – The water surface elevation downstream of a hydropower plant is used in computing head. The tailwater elevation may be entered as a constant on a *HP* record, or alternatively a table of tailwater elevation versus discharge (*TE/TQ* records) may be entered.

**TAMUWRAP** – The original 1988 version of the WRAP model was called the *Texas A&M University Water Rights Analysis Program (TAMUWRAP)*.

**target** – Diversion, instream flow, or hydroelectric power generation demand/need/requirement associated with a water right. *WR*, *UC*, *DI*, *SO*, *TO*, *TS*, and *FS* records provide options for use in setting targets. The water right type 7 feature (*WR* record field 6) allows reservoir storage targets to be set in the same manner as diversion targets but limited to not exceed the conservation storage capacity. Targets are met to the extent allowed by water availability.

**target series** – Diversion, instream flow, and hydropower requirements are typically modeled as varying seasonally but being constant from year to year. However, the target series *TS* record allows specifying targets that vary between years as well as between months.

**time interval** – The version of *WRAP* documented by this manual uses a computational time step of one month. Expanded features documented by the *Supplemental Manual* allow use of a daily or other sub-monthly time interval.

**transient priority water right** – options activated by the *PX* record assign two priorities to a water right. Transient priority option 1 allows a return flow to be assigned a priority different than the diversion. Transient priority option 2 allows a right to be activated and deactivated at different points in the priority sequence.

**turbine capacity** – An optional discharge capacity entered on the *HP* record in volume/month may be input as an upper limit on the amount of water that can be released through the turbines to

generate energy each month. If not otherwise specified the turbine discharge capacity is assumed to be unlimited.

**turbine inlet elevation** – The optional inlet elevation entered on a *HP* record sets a minimum pool level below which power generation is curtailed. Power generation with all releases for all rights is constrained by the turbine inlet invert. Releases for a particular right are also constrained by the specified inactive pool. For a hydropower right with the inactive pool set higher than the turbine inlet, power generation with pass-through flows and water supply releases for other rights are constrained only by the turbine inlet elevation. Additional releases for the hydropower right are also constrained by the specified inactive pool.

**type** – The water right type defined in *WR* record field 6 specifies certain water management tasks and rules associated with the water right.

**type 1 water right** – allows a water supply diversion target and/or storage target in one reservoir to be met from streamflow depletions and releases from one or multiple reservoirs.

**type 2 water right** – is the same as a type 1 right except a reservoir storage target (refilling of storage capacity in the one reservoir) is not allowed.

**type 3 water right** – is the same as a type 2 right except the permitted diversion target can be met only from reservoir releases from storage, not streamflow.

**type 4 water right** – the target amount of water is discharged into the stream.

**type 5 water right** – is the same as a type 1 right except a hydroelectric energy generation target is specified rather than a diversion. Hydropower rights are either type 5 and or type 6.

**type 6 water right** – is the same as a type 3 right except a hydroelectric energy generation target is specified rather than a diversion. Same as type 5 except not allowed streamflow depletions.

**type 7 water right** – sets a reservoir storage target.

**unappropriated streamflows** –*SIM* computed unappropriated flows, associated with a particular control point, are the portions of the naturalized streamflows still remaining after the streamflow depletions are made and return flows are returned for all the water rights included in the simulation. The *SIM* simulation starts with naturalized flows and computes regulated and unappropriated flows. Unappropriated flows may be less than regulated flows because a portion of the regulated flows may be committed to meet instream flow requirements or downstream diversion or storage rights.

**Users Manual** – TWRI Technical Report 256 entitled *Water Rights Analysis Package Modeling System Users Manual* provides instructions for working with input files and records.

**volume reliability** – The total volume of actual diversions or total hydroelectric energy generated during the simulation period-of-analysis expressed as a percentage of the corresponding total permitted diversion or hydroelectric energy targets. Computed based on Equation 5.1.

**water right** – A *WRAP* water right is a set of water management capabilities and water use requirements associated with either a water right *WR* record or instream flow *IF* record and supplemental records associated with the *WR* or *IF* record. A water right may include specifications for water supply diversion, return flow, hydroelectric energy generation, instream flow, and/or reservoir storage.

**water use distribution coefficients** – Each annual diversion, instream flow, and hydropower target is distributed over the 12 months of the year by a set of 12 multiplier factors entered on *UC* records.

**water surface elevation** – Reservoir water surface elevations determined based on linear interpolation of *PV/PE* record table are included in the OUT file on reservoir/hydropower records for all reservoirs for which *PV/PE* records are entered regardless of whether hydropower rights are associated with the reservoir. Reservoir water surface elevations are tabulated by the *TABLES 2WSE* record.

**watershed flow option** – This *SIM* option restricts the amount of water available to a water right to naturalized streamflow at its location computed by multiplying the naturalized flows input for the control point assigned to the water right by a factor which typically will be a drainage area ratio. Multiple water rights assigned to the same control point can have different limits on the amount of naturalized streamflow available to them.

**WinWRAP** – The user interface facilitates executing the WRAP programs within Microsoft Windows in combination with other Microsoft programs.

**WRAP** – The term *Water Rights Analysis Package (WRAP)* refers to the set of computer programs, *WinWRAP*, *TABLES*, *SIM*, *SIMD*, *HYD*, *DAY*, and *SALT* and associated documentation.

**WRAP2** and **WRAP3** – The 1992 *Water Rights Analysis Program-Version 2 (WRAP2)* in combination with *TABLES* replaced the original *TAMUWRAP* and was superseded by *WRAP3* which provided essentially all the capabilities of *WRAP2* plus multiple-reservoir system operation, hydroelectric power, and other optional features not available in *WRAP2*. *WRAP3* is superseded by *WRAP-SIM*.

**WRAP-DAY** – Pre-simulation utility program used to develop hydrology input for *WRAP-SIMD*.

**WRAP-HYD** – Pre-simulation utility program is used to develop hydrology input for *WRAP-SIM*.

**WRAPNET** – *WRAPNET* completed in 1993 provides the same modeling capabilities as *WRAP2*, but the internal computations are performed using network flow programming, a computationally efficient form of linear programming.

**WRAP-SALT** – The original *WRAPSALT* completed in 1994 expands *WRAP3* to incorporate features for considering salinity in assessing water supply reliability. A completely redesigned *WRAP-SALT* completed in 2004-2006 reads a *SIM* output file and salinity input file and tracks salt loads and concentrations through the river/reservoir system.

**WRAP-SIM** – This main program simulates a river/reservoir/use water allocation system.

**WRAP-SIMD** – This expanded version of *SIM* has sub-monthly time step, flow forecasting, flow routing, and flood control operations added.

**WRAPVIEW** – The TNRCC and USGS developed *WRAPVIEW* in 1996 by combining *WRAP* with the *ArcView* Geographical Information System (GIS) software package. *WRAPVIEW* was never fully operational and is now obsolete.

**zones 1 and 2** – For purposes of specifying multiple-reservoir operating rules, reservoir active pools may be divided into an upper and lower zones illustrated in Figures 4.1 and 4.2 by use of *OR* records. Release decisions are based on balancing the storage contents of comparable zones in multiple reservoirs in terms of contents as a percentage of zone capacity.

**APPENDIX B**  
**WRAP-SIM/TABLES EXAMPLES**

**Introduction to Appendices B and C**

Examples are provided to illustrate the format and content of *WRAP* datasets. Hypothetical river systems are modeled. Simple rather than realistic numbers are used in the examples to facilitate tracking of the model computations. Simple expressions are also adopted for the alphanumeric identifiers of control points, reservoirs, and water rights. Any descriptive label may be used for these identifiers. Only a few of the many possible tables of simulation results are developed with *TABLES*. All of the types of tables are relevant for any of the examples. The selection of tables to present with each example was arbitrary. An effective way for users to familiarize themselves with *WRAP* is to experiment by adding various features of interest to the examples, rerunning the model, and analyzing the results to confirm that the model behaves as expected. Another larger more realistic example is presented in the *Fundamentals Manual* and expanded in the *Supplemental Manual*.

Example	<i>SIM</i> or <i>HYD</i> Input Files	<i>SIM</i> or <i>HYD</i> Input Records	<i>TABLES</i> Input Records
<i><u>WRAP-SIM and TABLES Examples Presented in Chapters 2 and 3</u></i>			
1	DAT	T1,JD,CP,WR,ED,FO,EV,ED	
2	DAT	T1,JD,JO,UC,CP,IF,WR, WS,SV,SA,IN,EV,ED	2SCP,2REL,2FRE,2FRQ, 2STO,2REG,2UNA
3	DAT	T1,JD,CP,WR,ED,FO,EV,ED	
<i><u>WRAP-SIM and TABLES Examples Presented in Appendix B</u></i>			
4	DAT, FLO, EVA, DIS	T1,T2,JD, UC,CP,IF,WR,WS, SV,SA,DI,IS,IP,IN,EV,FD,WP	PAGE,2REL, 2FRE,2FRQ,IDEN
5	DAT, FLO, EVA	JD, RO,UC,RF,CP,CI, IF, WR,WS,SO,TO,ML,MS,IN,EV	2SCP, 2REL, 2RES
6	DAT	T1,JD,RO,UC,CP,IF,WR,WS, HP,OR,SV,SA,PV,PE,IN,EV	2REL,2FRE,IDEN 2REG,2UNA
7	DAT, FLO	T1,T2,JD,JO,CP,IF, WR,WS,TO,TS, IN	2NAT,2REG,2STO, 2DIV,2SHT,IDEN
8	DAT	Features EA, EF, AF records.	2SWR,2SCP
9		Features FS record.	2TAR, 2DIV, 2REG, IDEN
10	DAT	JD,JO,PX,BU,WR,WS,CP	2TAR,IDEN,2XAV,2DEP
<i><u>WRAP-HYD Examples Presented in Appendix C</u></i>			
11	HIN, FLO, EVA	JC,CP,EP,AS,FA,RS,SC,ED,IN,EV	
12	HIN, FLO, EVA	JC,CP,EP,AS,FA,RS,SC,ED,EV	
13	HIN, FLO, EVA	JC,CI,SV,SA,EP,AS,FA,RS,SC,IN,EV	
14	HIN, FLO, DIS, HYD	JC,CP,ED,IN,EV,FD,FC,WP	
15	HIN, OUT	JC, OI, ED	

The input files for the 15 examples are distributed with the software. Examples 1 and 2 are presented in Chapter 2. Example 3 is discussed in Chapter 3. Appendix B consists of Examples 4, 5, 6, 7, 8, 9, and 10 illustrating *SIM* and *TABLES*. Five examples demonstrating use of *HYD* are presented in Appendix C. *HYD* and *SIM* both contain several of the same computational routines. Thus, some of the *HYD* options, such as transferring stream flows from gaged to ungaged sites, illustrated by the *HYD* examples are also pertinent to *SIM* and vice versa.

### **WRAP-SIM and TABLES Examples 1, 2, 3**

The *SIM* and *TABLES* input and output data for Example 2 are included in the presentation in Chapter 2. The input files for Examples 1 and 3 are distributed with the other examples. However, the discussions of Examples 1 and 3 in Chapters 2 and 3 focus on specific aspects of the simulation computations and do not include actual data files. Example 1 addresses fundamental water rights loop computational algorithms in *SIM*. Example 3 focuses specifically on negative incremental flow adjustments. The set of example input files distributed with the model also includes a modified version of Example 3 revised to include synthesized stream flows. All of the *SIM* examples include the required *TI*, *JD*, *CP*, *WR* or *IF*, *ED*, and *IN* records. Examples 1 and 3 are limited to these basic types of records along with *JO* and *EV* records. The other examples include various other input records and associated modeling features.

### **WRAP-SIM and TABLES Example 4**

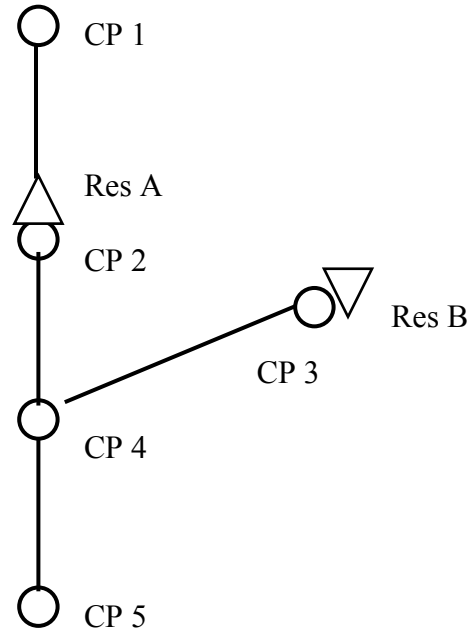
Default input and output files are used in Example 4; thus, a *JO* record *INEV* entry is not required. Input data files are printed on the following pages. Filenames are exam4.DAT, exam4H.FLO, exam4H.EVA, and exam4H.DIS. *SIM* creates output files with filenames exam4.OUT and exam4.MSS. Neither is reproduced here. The message file (filename exam4.MSS) provides the trace messages shown in the *Users Manual* indicating the simulation progressed to a normal completion. *TABLES* reads the file exam4.OUT and organizes the simulation into selected tables. *TABLES* input and output files (filenames exam4.TIN and exam4.TOU) are reproduced here following the *SIM* input. The spatial configuration of the river basin system is shown in the schematic on the next page.

#### **Hydrology for Example 4**

A 3-year 1996-1998 hydrologic period-of-analysis is adopted. A 50 to 80 year period-of-analysis would be more representative of actual modeling applications, but we need to keep the examples small. Naturalized stream flows, in acre-feet/month, are provided as input on *IN* records for control points CP-2, CP-3, and CP-5. Naturalized stream flows at CP-1 are synthesized by transferring flows from CP-2 using the modified NRCS CN method. Flows at CP-4 are synthesized by applying the drainage area ratio method with channel losses to the incremental flows at CP-5 from the subwatershed below CP-2 and CP-3. Channel loss factors of 0.10, 0.12, and 0.15, respectively, are entered on the *CP* records for CP-2, CP-3, and CP-4.

Net evaporation-precipitation depths in inches are provided on *EV* records for CP-2. These depths are converted to feet by the multiplier factor in field 5 of the *CP* record. Net

evaporation-precipitation depths for CP-2 are repeated for CP-3 by *CP* record field 7. Since there are no reservoirs at CP-1, CP-4, and CP-5, *NONE* is entered in *CP* record field 7.



**System Schematic for Example 4**

Water Rights for Example 4

Information for the seven water rights is tabulated below.

Water Right	Water Right Owner	Location	Reservoir	Priority Number	Refilling Capacity (acre-feet)	Permitted Diversion (ac-ft/yr.)	Return Flow Factor	Instream Flow Requirement
WR-1	Mr. J. W. Smith	CP-1	-	1965	-	1,200	0.2	-
WR-2	Municipal District	CP-2	Res A	9999	80,000	-0-	-	-
WR-3	Irrigation District	CP-3	Res B	1975	30,000	42,000	0.1	-
WR-4	Irrigation District	CP-3	Res B	8888	40,000	40,000	0.35	-
WR-5	City of Jonesville	CP-4	Res A	1984	-0-	26,000	-	-
WR-6	Elm City	CP-5	Res A	1952	-0-	18,000	-	-
WR-7	State of Texas	CP-5	-	1111	-	-	-	12,000

Water right 1 is a run-of-river (no reservoir storage) irrigation diversion of 1,200 acre-feet/year at CP-1, distributed seasonally (*UC* records) as follows: 240 ac-ft in May and August and 360 ac-ft in June and July. Twenty percent of the water diverted each month is returned at CP-2. The priority number of 1965 represents the effective date of the water right permit.

Water right 3 includes a 42,000 ac-ft/year diversion from Reservoir B and filling storage to a capacity of 30,000 ac-ft with a priority number of 1975. Water right 4 consists of filling reservoir B to its full capacity of 40,000 ac-ft with a priority junior to all diversion rights but senior to filling storage in Reservoir A.

Water rights 5 and 6 are diversions for municipal use by the cities of Jonesville and Elm City from stream flows at CP-4 and CP-5, respectively, supplemented as necessary by releases from Reservoir A. Their water right permits have effective dates of 1984 and 1952 which set their priorities. Reservoir A is refilled by water right 2 with a priority junior to all other rights, represented by a priority number of 9999 which is larger than the priority numbers of all other rights but otherwise arbitrary. Any time the storage content of Reservoir A drops to 20,000 ac-ft (25% of capacity), a municipal demand management plan is implemented which reduces the diversion requirements to 80% of normal.

Water right 7 is an instream flow target at CP-5 that varies as a function of total system storage and is modeled using the drought index feature (*DI/IS/IS* records). The instream flow target varies linearly from 500 ac-ft/month (6,000 ac-ft/year) when both reservoirs are empty to 1,000 ac-ft/month (12,000 ac-ft/year) when the total storage is 60,000 ac-ft (50% of capacity). If the total storage content is between 60,000 and 108,000 ac-ft, the instream flow requirement is set at 1,000 ac-ft/month. If storage rises above 108,000 ac-ft, the flow target increases to 1,200 ac-ft/month. The drought index is as follows.

Total Storage Content of Reservoirs A and B (acre-feet)	Instream Flow (ac-ft/month)	Instream Flow as a Percentage of 1,000 ac-ft/month
0	500	50%
60,000	1,000	100%
60,000 to 108,000	1,000	100%
108,001 to 120,000	1,200	120%

#### WRAP-SIM DAT File for Example 4

```

T1 Example 4 - WRAP-SIM Input File Exam4.DAT
T2 Example 4 from Appendix B of Reference Manual
**
** Fixed-Width Fields and Columns
** 2 ! 3 ! 4 ! 5 ! 6 ! 7 ! 8 ! 9 ! 10 !
** 3-8 ! 9-16 ! 17-24 ! 25-32 ! 33-40 ! 41-48 ! 49-56 ! 57-64 ! 65-72 !
**
JD 3 1996 1 -1 -1
**
** Water Use Coefficients
**
UC mun 0.06 0.06 0.06 0.06 0.06 0.10
UC 0.12 0.12 0.11 0.10 0.09 0.06
UC irr 0.00 0.00 0.00 0.00 0.20 0.30
UC 0.30 0.20 0.00 0.00 0.00 0.00

```

**Continuation of WRAP-SIM DAT File for Example 4**

```

**
**      Control Points
**
CP  CP-1    CP-2                4                NONE
CP  CP-2    CP-4      0.083333    0                0.10
CP  CP-3    CP-4                0                CP-2      0.12
CP  CP-4    CP-5                6                NONE      0.15
CP  CP-5    OUT                0                NONE
**      ! 1      ! 2      ! 3      ! 4      ! 5      ! 6      ! 7      !
**3456789012345678901234567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !      !
**      Water Rights
**
WR  CP-1    1200    irr    1965                0.2                WR-1
**
WR  CP-2                9999                WR-2
WS Res A    80000
**
WR  CP-3    42000    irr    1975                0.1                WR-3
WS Res B    30000
WR  CP-3                8888                WR-4
WS Res B    40000
**
WR  CP-4    26000    mun    1984    2                0.35                2    WR-5
WS Res A    80000
**
WR  CP-5    18000    mun    1952    2                2    WR-6
WS Res A    80000
**
IF  CP-5    12000                0                1    WR-7
**
**      Reservoir Storage Volume versus Surface Area Tables
**
SV Res A    0    825    2980    8640    22100    42700    73700    89600
SA          0    112    327    920    1760    2480    3750    4930
**
SV Res B    0    740    2680    7780    19800    38400    52900
SA          0    100    298    832    1580    2230    2690
**
**      Drought Indices
**
DI      1    -1
IS      5    0    60000    108000    108001    120000
IP          50    100    100    120    120
**
DI      2    1    Res A
IS      4    0    20000    20001    800000
IP          80    80    100    100
**
**      !      !      !      !      !      !      !      !      !
**3456789012345678901234567890123456789012345678901234567890123456789012
**      1      2      3      4      5      6      7
ED

```



## WRAP-SIM FLO File for Example 4

```

** Example 4 - WRAP-SIM Input File Exam4H.FLO
** Example 4 from Appendix B of Reference Manual
**
** Naturalized Monthly Streamflows in acre-feet
**
IN CP-2 1996 10800 12500 8100 7620 9610 1200 850 2540 9520 1850 1760 7200
IN CP-3 1996 5200 6280 3750 3970 4450 750 1090 2160 4670 915 850 3490
IN CP-5 1996 19400 24600 14200 15200 18400 2640 2290 6240 21800 3780 3720 13900
**
IN CP-2 1997 6250 8140 4190 7280 6930 1390 725 545 942 1890 4910 5740
IN CP-3 1997 2180 4320 3760 2350 3760 870 915 296 1020 2250 4870 3190
IN CP-5 1997 11200 17800 10620 14500 15400 2930 1910 1290 2300 5190 12800 13700
**
IN CP-2 1998 7680 6590 5570 5230 6180 1280 1670 1050 7890 8670 6210 5360
IN CP-3 1998 3820 3540 2190 2310 3290 657 845 840 3970 4230 3540 2870
IN CP-5 1998 15400 13900 18300 9780 12600 2560 3420 2650 15400 17400 12700 11800

```

## WRAP-SIM EVA File for Example 4

```

** Example 4 - WRAP-SIM Input File Exam4H.EVA
** Example 4 from Appendix B of Reference Manual
**
** Net Evaporation-Precipitation Rates in Inches
**
EV CP-2 1996 3.2 2.8 3.1 -1.6 -3.7 1.9 4.3 3.9 2.5 1.9 1.6 2.9
EV CP-2 1997 2.5 1.7 -4.9 -0.9 -2.1 0.7 3.5 2.8 3.1 2.5 0.9 2.6
EV CP-2 1998 2.9 2.1 -1.5 -2.8 -2.6 -0.2 2.7 -1.4 2.2 2.1 2.0 1.9

```

## WRAP-SIM DIS File for Example 4

```

** Example 4 - WRAP-SIM Input File Exam4H.DIS
** Example 4 from Appendix B of Reference Manual
**
** Flow Distribution Information
**
FD CP-4 CP-5 2 CP-2 CP-3
FD CP-1 CP-2
**
WP CP-1 225 74 31
WP CP-2 398 69 31
WP CP-3 194
WP CP-4 650
WP CP-5 715
ED

```

### TABLES Input File for Example 4

```

COMM TABLES Input File Exam4.TIN
COMM Example 4 from Appendix B
PAGE
2REL
2FRE 1
2FRE 2
2FRE 3
2FRE 4 0 2
IDEN CP-2 CP-3
2FRQ 3 0 7 CP-5 200,2000,5000,8000,10000,15000,20000,
2SBA
ENDF

```

### TABLES Output File for Example 4

```

*****
**                                     **
**           Water Rights Analysis Package           **
**                   TABLES                   **
**           March 2008 Version                   **
**                                     **
*****

```

Title records from WRAP-SIM output file:

Example 4 - WRAP-SIM Input File Exam4.DAT  
 Example 4 from Appendix B of Reference Manual

The program WRAP-SIM output file contains simulation results for:

- 7 water rights
- 5 control points
- 0 reservoirs

for a period-of-analysis of 3 years beginning in 1996.

Program TABLES input file name: Exam4.TIN  
 Program TABLES output file name: Exam4.TOU

Root of SIM input and output file names: Exam4

### RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET	MEAN	*RELIABILITY*	PERCENTAGE OF MONTHS								PERCENTAGE OF YEARS							
	DIVERSION (AC-FT/YR)	SHORTAGE (AC-FT/YR)	PERIOD (%)	VOLUME (%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%	
CP-1	1200.0	710.07	33.33	40.83	33.3	33.3	41.7	41.7	41.7	50.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	
CP-2	0.0	0.00	There are no diversions at this control point.																
CP-3	42000.0	7336.29	66.67	82.53	66.7	66.7	75.0	75.0	83.3	83.3	100.0	33.3	33.3	33.3	33.3	66.7	100.0	100.0	
CP-4	26000.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
CP-5	18000.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
Total	87200.0	8046.36	90.77																

## FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
CP-1	4416.5	2601.	545.0	609.8	674.6	825.0	1006.8	1760.0	4519.	5033.	5548.	6421.	7732.	9745.
CP-2	5162.8	3314.	545.0	609.8	674.6	825.0	1006.8	1760.0	5038.	5740.	6454.	7680.	9556.	12500.
CP-3	2762.7	1572.	296.0	426.0	555.9	731.4	843.0	1020.0	2274.	3190.	3540.	3970.	4750.	6280.
CP-4	9546.4	5747.	1081.7	1339.6	1597.6	2073.6	2233.6	3213.8	9638.	11394.	12235.	13600.	17079.	22023.
CP-5	10881.1	6598.	1290.0	1513.2	1736.4	2214.0	2456.0	3720.0	10852.	12700.	13900.	15400.	18800.	24600.

## FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
CP-1	4375.6	2608.	545.0	609.8	674.6	825.0	1006.8	1760.0	4519.	5033.	5548.	6421.	7600.	9745.
CP-2	4751.8	2977.	0.0	0.0	0.0	0.0	1018.7	2682.6	3807.	4692.	5691.	7010.	8780.	11516.
CP-3	493.7	1450.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	3606.	5748.
CP-4	5302.0	4720.	385.8	391.2	396.5	591.4	911.5	1617.8	1965.	4261.	5615.	8916.	12826.	19109.
CP-5	6531.7	5555.	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	3714.	6724.	7275.	11066.	14946.	21589.

## FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
CP-1	2981.4	3173.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2784.	4679.	5648.	7281.	9745.
CP-2	3529.7	3818.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2784.	5453.	7010.	8780.	11516.
CP-3	493.7	1450.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	3606.	5748.
CP-4	4773.8	5181.	0.0	0.0	0.0	0.0	0.0	0.0	970.	4261.	5615.	8916.	12826.	19109.
CP-5	5492.8	5510.	0.0	0.0	0.0	0.0	0.0	0.0	2714.	5724.	6275.	9866.	13826.	20389.

## STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE										MAXIMUM	
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%		10%
CP-2	76936.	4973.	62010.	62537.	63064.	66029.	70227.	75835.	78710.	80000.	80000.	80000.	80000.	80000.
CP-3	16284.	12057.	291.	462.	632.	830.	1131.	8304.	11984.	14826.	17707.	23803.	40000.	40000.
Total	93220.	15454.	64760.	65023.	65286.	67822.	74457.	84759.	89790.	93203.	97707.	103203.	120000.	120000.

## FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS FOR CONTROL POINT CP-5

FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)
200.0	66.67	2000.0	58.33	5000.0	52.78	8000.0	30.56	10000.0	22.22	15000.0	5.56	20000.0	2.78

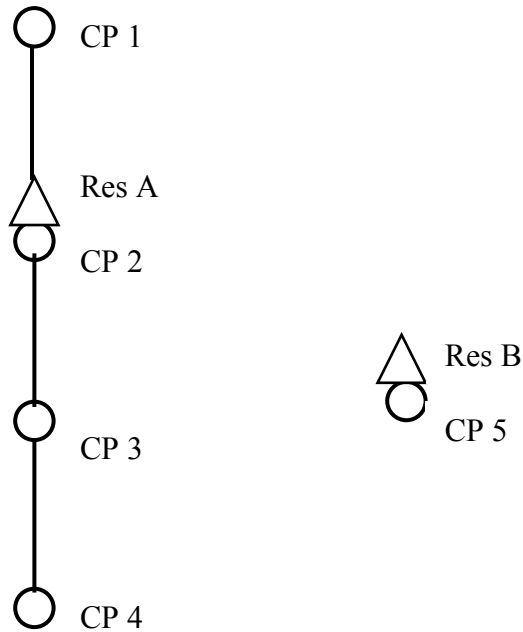
## ANNUAL SUMMARY TABLE FOR THE RIVER BASIN

Note: For naturalized streamflow and unappropriated flow, the quantities shown represent the maximum flow at any control point in a given month, based on comparing all control points. All other quantities shown are the sum of the values for all the control points.

YEAR	NATURALIZED	RETURN	STREAMFLOW	UNAPPROPRIATED	EOP	EVAPORATION (AC-FT)	TARGET	ACTUAL	DIVERSION
	STREAMFLOW (AC-FT)	FLOW (AC-FT)	DEPLETION (AC-FT)	FLOW (AC-FT)	STORAGE (AC-FT)		DIVERSION (AC-FT)	DIVERSION (AC-FT)	SHORTAGE (AC-FT)
1996	146170.0	13396.0	73154.1	84933.0	95181.7	10228.2	87200.0	86480.0	720.0
1997	109640.0	12553.6	71755.3	50464.9	82921.8	3506.9	87200.0	78125.7	9074.3
1998	135910.0	12043.5	88504.1	62929.9	94918.9	2660.1	87200.0	72855.2	14344.7
MEAN	130573.3	12664.4	77804.5	66109.3	91007.5	5465.1	87200.0	79153.6	8046.4

## WRAP-SIM and TABLES Example 5

The *SIM* input data for Example 5 are stored in files, with filenames exam5.DAT, exam5.FLO, and exam5.EVA, which are printed on the following pages. *TABLES* input and output files (filenames exam5.TIN and exam5.TOU) are also shown. A two-year 2006-2007 hydrologic period-of-analysis is adopted. A system schematic is provided below. Control point CP 5 is located in a separate river basin from the other control points. Very simple numbers are used in this example to facilitate manual tracking of the simulation computations. Comment \*\* records inserted in the exam5.DAT file describe the various groups of records.



**System Schematic for Example 5**

### **WRAP-SIM DAT File for Example 5**

```
T1 WRAP-SIM Input File Exam5.DAT
T2 Example 5 from Appendix B of Reference Manual
**
** The default DAT, INF, EVA input files and OUT and MSS output files
** are used, but there is no DIS file.
**
JD      2      2006      1      -1      -1
**
** The -1's on the JD record result in output for all water rights and control
** points. The following RO record results in output for the two reservoirs.
**
RO      2      Res A      Res B
**
** Constant use factors distribute an annual diversion uniformly over the year.
** Since this is the model default, the following UC records are not required.
**
UC const      1      1      1      1      1      1
UC            1      1      1      1      1      1
**
```

```

** RF records allow return flow factors to vary over the 12 months of the year.
**
RF rflow      0.2      0.2      0.2      0.0      0.0      0.0
RF           0.3      0.3      0.3      0.25     0.25     0.25
**
** Loss CL factors of 0.25 and 0.3 are input in field 10 of the CP records
** for CP1 and CP2. The watershed area of 1,000 acres entered in field 9
** for CP2 is used in determining the adjusted net evap-precip for RES1.
** Field 8 indicates there are no EV records for CP1, CP3, and CP4.
**
CP  CP1      CP2      NONE      0.25
CP  CP2      CP3      1000.     0.30
CP  CP3      CP4      none
CP  CP4      OUT      zero
CP  CP5      OUT      CP2
**
** An inflow of 20 acre-feet/month enters the river system at CP1.
**
CI  CP1      20      20      20      20      20      20
CI  CP1      20      20      20      20      20      20
**
** Instream flow requirement IF1 sets a minimum regulated flow target of
** 70 ac-ft/month at CP3. With a priority number of 1900, IF1 is senior
** to all of the other rights except IF4.
**
IF  CP3      840      const    1900      2      IF1
**
** Return flow options 4 and 1 are adopted for water rights WR1 and WR2a.
**
WR  CP1      360      const    1985      3      rflow      WR1
WR  CP2      840      const    1980      0.2     0.2         WR2a
WS Res A    200      0.1      1      0.      400
**
** WR2a refills storage in reservoir Res A to 200 ac-ft with a 1980 priority.
** WR2b fills Res A to full capacity of 500 ac-ft, subject to limits imposed
** by the MS records, with a priority junior to all other rights.
**
WR  CP2      0      const    3000      WR2b
WS Res A    500      400
**
** Releases from Res A are made, if necessary, to meet a instream flow target
** of 30 ac-ft/month set by IF2. RESA passes inflows but does not release
** from storage for the IF1 target of 70 ac-ft/month.
**
IF  CP3      360      const    2000      3      IF2
WS Res A    500      400
**
** The final unappropriated flows are based on the IF1 instream flow
** requirement of 70 ac-ft/month at CP3, which is repeated as IF3 with a
** priority junior to all rights except the WR2b reservoir refilling right.
**
IF  CP3      840      const    2100      2      IF3
**
** A minimum flow at CP5 must be maintained of 50 percent of the CP5 naturalized
** streamflow. The minimum flow at CP5 must also be at least 2 percent of the
** regulated flow at CP4. This is the most senior right in the model.
**
IF  CP5      1800      2      IF4
TO  1      0.5      CP5      CONT
TO  2      0.02     MAX     CP4
**
** Res B is located at CP5 and is filled from streamflow at CP4 as well as CP5.
** WR3a includes both storage in Res B and a 20 ac-ft/month diversion at CP5.
** WR3b allows filling of Res B at CP5 by depleting streamflows from CP4.
** The CP4 streamflow depletion has both monthly and annual limits.
**
WR  CP5      240      const    8888      WR3a
WS Res B    100      0.1      1      0.0
WR  CP5      0      const    9999      WR3b
WS Res B    100
SO           350      CP4

```

```

ML      5      0      0      5      15      15      200      200      200      200      200      200
**
** A seasonal rule curve operating plan is in effect for reservoir Res A.
** Storage is limited to 400 ac-ft from October through March and limited
** to 500 ac-ft from April through September.
**
MS Res A 400,400,400,500,500,500,500,500,500,400,400,400
**
** The hydrology (IN and EV) records are in files Exam5.FLO and Exam5.EVA.
**
ED

```

### WRAP-SIM FLO File for Example 5

```

** WRAP-SIM Input File Exam5.FLO
** Example 5 from Appendix B of Reference Manual
**
** Naturalized Streamflows
** The flows for 2006 illustrate the optional comma delimited format.
**
IN CP1 ,2006 60,60,60,80,80,80,30,30,30,90,90,90,
IN CP2 ,2006 100,100,100,120,120,120,50,50,50,150,150,150,
IN CP3 ,2006 130,130,130,160,160,160,80,80,80,200,200,200,
IN CP4 ,2006 190,190,190,220,220,220,140,140,140,260,260,260,
IN CP5 ,2006 10,10,10,10,10,10,10,10,10,10,10,10,
**
IN CP1 2007 60 60 60 0 0 0 120 120 120 60 60 60
IN CP2 2007 100 100 100 0 0 0 200 200 200 100 100 100
IN CP3 2007 130 130 130 0 0 0 260 260 260 130 130 130
IN CP4 2007 190 190 190 60 60 60 320 320 320 190 190 190
IN CP5 2007 10 10 10 10 10 10 10 10 10 10 10 10

```

### WRAP-SIM EVA File for Example 5

```

** WRAP-SIM Input File Exam5.EVA
** Example 5 from Appendix B of WRAP Reference Manual
** Net Evaporation-Precipitation Rates
**
EV CP2 2006 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
EV CP2 2007 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5

```

### TABLES Input File for Example 5

```

COMM TABLES Input File Exam5.TIN
COMM Example 5 from Appendix B of Reference Manual
2SCP
2REL 1
2RES 0 0 2 Res A Res B
2RES 500 100
ENDF

```

### TABLES Output File for Example 5

#### ANNUAL SUMMARY TABLE FOR CONTROL POINT CP1

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2006	780.0	670.0	96.2	0.0	350.0	0.0	0.0	350.0	10.0
2007	720.0	690.0	84.0	0.0	270.0	0.0	0.0	270.0	90.0
MEAN	750.0	680.0	90.1	0.0	310.0	0.0	0.0	310.0	50.0

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP2

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2006	1260.0	119.3	72.1	64.5	1122.7	400.0	282.7	840.0	0.0
2007	1200.0	159.2	90.7	67.5	1168.5	400.0	245.8	840.0	0.0
MEAN	1230.0	139.3	81.4	66.0	1145.6	400.0	264.2	840.0	0.0

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP3

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2006	1710.0	1079.5	239.5	168.0	0.0	0.0	0.0	0.0	0.0
2007	1560.0	999.5	279.5	184.5	0.0	0.0	0.0	0.0	0.0
MEAN	1635.0	1039.5	259.5	176.2	0.0	0.0	0.0	0.0	0.0

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP4

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2006	2430.0	1573.0	1573.0	0.0	226.5	0.0	0.0	0.0	0.0
2007	2280.0	1489.4	1489.4	0.0	230.1	0.0	0.0	0.0	0.0
MEAN	2355.0	1531.2	1531.2	0.0	228.3	0.0	0.0	0.0	0.0

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP5

YEAR	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
2006	120.0	61.2	0.0	0.0	58.8	100.0	45.2	240.0	0.0
2007	120.0	64.8	0.0	0.0	55.2	100.0	45.2	240.0	0.0
MEAN	120.0	63.0	0.0	0.0	57.0	100.0	45.2	240.0	0.0

RELIABILITY SUMMARY FOR SELECTED WATER RIGHTS

NAME	TARGET	MEAN	*RELIABILITY*	+++++ PERCENTAGE OF MONTHS +++++							----- PERCENTAGE OF YEARS -----					
	DIVERSION SHORTAGE (AC-FT/YR)	SHORTAGE (AC-FT/YR)	PERIOD VOLUME (%)	WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT							PERCENTAGE OF TARGET DIVERSION AMOUNT					
			(%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%
WR2a	840.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
WR1	360.0	50.00	75.00	86.11	75.0	75.0	75.0	87.5	87.5	87.5	87.5	0.0	0.0	50.0	50.0	100.0
WR2b	This water right has no diversion target.															
WR3a	240.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
WR3b	This water right has no diversion target.															
Total	1440.0	50.00	96.53													

END-OF-PERIOD RESERVOIR STORAGE AS A PERCENTAGE OF CAPACITY

Percentage = 100% \* (S - C2) / (C1 - C2) where  
 S = end-of-month storage  
 C1,C2 = user defined top and bottom of storage zone

YEAR	MONTH	MEAN	Res A	Res B
2006	1	82.50	80.00	85.00
2006	2	73.00	80.00	66.00
2006	3	64.00	80.00	48.00
2006	4	59.70	83.40	36.00
2006	5	60.30	86.60	34.00
2006	6	61.30	89.60	33.00
2006	7	89.20	78.40	100.00
2006	8	83.90	67.80	100.00
2006	9	78.90	57.80	100.00
2006	10	84.80	69.60	100.00
2006	11	90.00	80.00	100.00
2006	12	90.00	80.00	100.00
2007	1	82.50	80.00	85.00
2007	2	73.00	80.00	66.00
2007	3	64.00	80.00	48.00
2007	4	48.40	60.80	36.00
2007	5	38.30	42.60	34.00
2007	6	29.20	25.40	33.00
2007	7	74.50	49.00	100.00
2007	8	85.60	71.20	100.00
2007	9	95.90	91.80	100.00
2007	10	90.00	80.00	100.00
2007	11	90.00	80.00	100.00
2007	12	90.00	80.00	100.00

RESERVOIR STORAGE DRAWDOWN DURATION

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	NUMBER OF PERIODS WITH DRAWDOWNS EQUALING OR EXCEEDING PERCENT OF ZONE STORAGE CAPACITY								
				0%	2%	5%	10%	25%	50%	75%	90%	100%
Res A	365.42	0.	500.	24.	24.	24.	23.	8.	3.	0.	0.	0.
Res B	75.17	0.	100.	24.	12.	12.	12.	10.	8.	0.	0.	0.

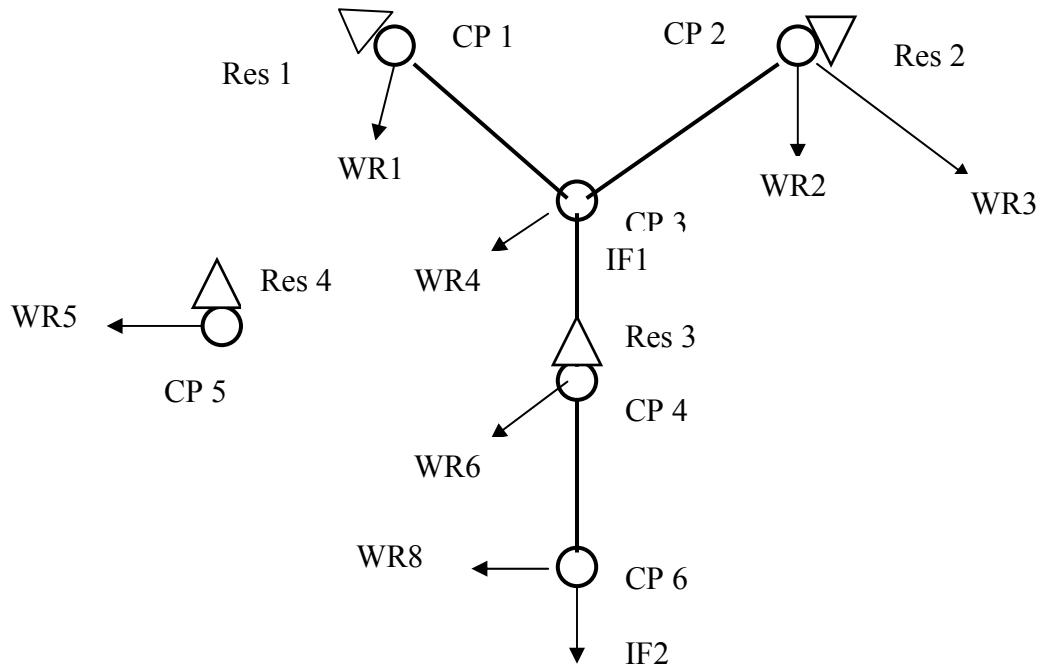
RESERVOIR STORAGE RELIABILITY

NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING PERCENTAGE OF STORAGE CAPACITY								
				100%	98%	95%	90%	75%	50%	25%	10%	>0%
Res A	365.42	0.	500.	0.0	0.0	0.0	4.2	66.7	87.5	100.0	100.0	100.0
Res B	75.17	0.	100.	50.0	50.0	50.0	50.0	58.3	66.7	100.0	100.0	100.0



## WRAP-SIM and TABLES Example 6

The *WRAP-SIM* input data for Example 6 are stored in one file named exam6.DAT which is reproduced later. *TABLES* input and output files (filenames exam6.TIN and exam6.TOU) are also shown. As indicated by the schematic below, the system configuration includes five control points located in one river basin and another control point located in another river basin. There are eleven water rights and four reservoirs. Very simple numbers are used in this example to facilitate manual tracking of the simulation computations.



**System Schematic for Example 6**

### Hydrology for Example 6

A 1997-1998 hydrologic period-of-analysis is used. Naturalized stream flows are provided on *IN* records for each month of the two-year simulation at each of the six control points. The naturalized flows are in acre-feet/month at all of the control points except CP5, which are in units of thousand cubic meters per month. A conversion factor of 0.811 ac-ft/1,000 m<sup>3</sup> is provided on the *CP* record for CP5. The file and sequencing options for the *IN* and *EV* are defined in *JO* record field 2.

Reservoir net evaporation-precipitation rates are entered on *EV* records for control points CP1 and CP2. The data for CP1 are also used at CP4 and CP5 (*CP* record field 9). The rates are in units of feet/month for CP1 and inches/month at CP2. The *CP* record for CP2 includes a conversion of 0.0833 foot/inch. The *NONE* on the *CP* records for CP3 and CP6 indicate that no evaporation-precipitation data are provided or required.

**Example 6 Water Rights Listed in Priority Order**

Water Right ID	Water Right Type	Control Point ID	Return Flow Location	Diversion Target (ac-ft/yr)	Instream Flow (ac-ft/yr)	Primary Reservoir Identifier	Reservoir Capacity (ac-ft)	Secondary Reservoir Identifier
IF2	1	CP6			240			
IF1	1	CP3			120			
WR1	1	CP1	CP3	360		Res1	200	
WR2	1	CP2	CP3	60		Res2	50	
WR4	2	CP3		720				Res1 Res2
WR6	1	CP4		120				Res3
WR5a	2	CP5		600				Res3 Res4
WR5b	1	CP5				Res4	200	
WR3	1	CP2	CP3	180		Res2	250	
WR8	4	CP6	CP3	varies				Res1 Res2 Res3
WR7	5	CP4		*		Res3	300	

\* Permitted annual energy target for WR7 is 12,000 kilowatt-hours.

**Example 6 Reservoir Storage Capacity**

Reservoir Identifier	Primary or Secondary (P or S)	Water Right Identifier	Storage Capacity to Refill (ac-ft)	Inactive Pool Capacity (ac-ft)	Capacity at Top of	
					Zone 1	Zone 2
Res1	P	WR1	200	10	200	200
	S	WR4		10		
	S	WR8		10		
Res2	P	WR2	50	25	250	150
	P	WR3		25		
	S	WR4		25		
	S	WR8		25		
Res3	P	WR6	300	30	300	165
	P	WR9		30		
	S	WR4		30		
	S	WR5b		150		
	S	WR8		30		
Res4	S	WR5a	200		200	100
	P	WR5b				

### Volume versus Area Relationships for the Example 6 Reservoirs

A storage volume versus water surface area relationship is required for each of the four reservoirs for use in the evaporation computations. A table of storage volume, in acre-feet, versus area, in acres, is provided on *SV* and *SA* records for reservoir Res4.

The storage-volume relationships for the other three reservoirs are provided by the alternative option of entering the coefficients for Equation 7-1 in fields 4, 5, and 6 of the *WS* record. With values of 0.1, 1.0, and 0.0 for coefficients *a*, *b*, and *c*, respectively, for each of these reservoirs, Equation 7-1 reduces to:

$$\text{area in acres} = 0.1 (\text{storage volume in acre-feet})$$

### Water Rights for Example 6

Information associated with each water right is summarized in the tables on the next page. Diversion, instream flow, and hydropower requirements are provided in the first table. Reservoir storage capacities are tabulated in the second table.

Water Rights IF1 and IF2. - Water rights IF1 and IF2 are instream flow requirements at control points CP3 and CP6, respectively, of 120 ac-ft/year (10 ac-ft/month) and 240 ac-ft/year (20 ac-ft/month). With priority numbers of 191805 (May 1918) and 191803 (March 1918), these are the two most senior rights in the system.

Water Right WR1. - Water right WR1 located at control point CP1 has a permitted diversion of 360 ac-ft/yr, priority number of 192602 representing February 1926, and same-month return flow of 20% reentering the river at CP3. The annual diversion amount is converted to monthly diversions using the default constant monthly use factors. WR1 is a type 1 right with RES1 being its primary and only reservoir. Reservoir Res1 can be filled to a capacity of 200 ac-ft and supply water for the WR1 diversion until the storage level drops below the inactive pool capacity of 10 ac-ft. The volume-area relationship coefficients must be entered with WR1 since this is the first time Res1 is cited but do not have to be repeated on subsequent Res1 *WS* records.

Water Rights WR2 and WR3. - Res2 is the primary (and only) reservoir for both WR2 and WR3, which can refill it to total cumulative capacities of 50 and 250 ac-ft, respectively. WR2 and WR3 have permitted annual diversion amounts of 60 and 180 ac-ft/yr, respectively, which are met by CP2 inflows as long as yet unappropriated stream flow is available and then withdrawals from Res2 as long as the storage is above the inactive pool capacity of 25 ac-ft. WR3 is junior to WR2. Several other rights at other locations have priorities which fall between WR2 and WR3.

Water Right WR4. - WR4 is a type 2 right with two secondary reservoirs but no primary reservoir. The WR4 diversion target is 720 ac-ft/yr or 60 ac-ft/month at CP3. Return flows of 40% the diversion amount reenter the river at the default next downstream control point.

The WR4 diversion target is met first by available stream flow at CP3 and then, as necessary, by releases from reservoirs Res1 and Res2. WR4 is denoted a type 2 right since

(unlike a type 1 right) it does not refill reservoir storage and (like a type 1 but unlike a type 3 right) it makes releases from Res1 and Res2 only if sufficient stream flow is not available at CP3 for the diversion.

Multiple-reservoir system operations are based on balancing the storage, as a percent of zone capacity, in each reservoir. *WRAP-SIM* computes a ranking index for each reservoir using Equation 4.2.

$$\text{rank index} = (\text{multiplier factor}) \left[ \frac{\text{storage content in zone}}{\text{storage capacity of zone}} \right] + \text{addition factor} \quad (4.2)$$

The release is made from the reservoir with the greatest value for the rank index. The reservoir zones are defined by Figure 4.1. Zone 1 must be empty in all the reservoirs in the system in order for releases to be made from zone 2 of any of the reservoirs.

The weighting factors used in the above formula are entered for each reservoir on the *OR* records. Weighting factors of either 1.0 or zero are used for the two zones of all reservoirs in the example. Since only the relative magnitude between reservoirs matters, replacing the 1.0's with any positive constant number will yield the same result. Since the zeroes are assigned to zones with zero storage capacity, any other number will yield the same result.

For water right WR4, the Res2 cumulative storage capacities at the top of inactive zone, active zone 2, and active zone 1 are 25 ac-ft, 125 ac-ft, and 250 ac-ft. Thus, zones 1 and 2 have capacities of 125 ac-ft (250-125), and 100 ac-ft (125-25), respectively. Res1 has cumulative storage capacities at the top of inactive zone, active zone 2, and active zone 1 of 10, 200, and 200 ac-ft, respectively. Since *WS* record field 3 and *OR* record field 3 both contain values of 200 ac-ft, Res1 zone 1 contains zero storage capacity. In order for a release to be made from Res1, the storage contents of Res2 must be below 125 ac-ft.

Water Rights WR5a and WR5b. Since multiple-reservoir release decisions are pertinent only to secondary reservoirs and storage capacity can be replenished only in a primary reservoir, WR5 is treated as two separate water rights WR5a and WR5b. Water right WR5a has a diversion of 50 ac-ft/month (600 ac-ft/yr.) located at CP5 which is met by available stream flow at CP5 supplemented by releases from reservoirs Res3 and Res4. WR5b refills storage in Res4 from available stream flow. WR5b is assigned a priority junior to WR5a so that the Res4 storage capacity is refilled after, rather than before, the WR5a diversion and associated release decisions are completed.

With the exception of Res4, the reservoirs are full at the beginning of the simulation on 1 January 1997. The storage content of Res4 is 100 ac-ft when the simulation begins.

The WR5a diversion is supplied by water from the following sources in the order listed:

- (1) stream flows at CP5 (inflows to Res4) until the stream flow is depleted
- (2) releases or withdrawals from Res4 until the reservoir is emptied to less than half of its storage capacity

- (3) releases and withdrawals from both Res3 and Res4 until Res3 is emptied to less than half of its storage capacity and Res4 is empty

When both Res3 and Res4 are supplying water, release decisions are based on balancing the percent full (or percent depleted) of specified zones consisting of the lower half of Res4 and the upper half of Res3. Shortages occur if the indicated stream flow and reservoir storage is insufficient to meet the permitted diversion. This WR5a multiple-reservoir operating policy is defined in the *WRAP-SIM* input file as follows. Active pool zone 1 (Figure 4-1) in Res4 has a capacity of 100 ac-ft since the total cumulative capacities at the top of zone 1 is 200 ac-ft and at the top of zone 2 (bottom of zone 1) is 100 ac-ft. The inactive pool has zero storage. Thus, the Res4 storage capacity is divided in half, with 100 ac-ft in the upper zone 1 and 100 ac-ft in the lower zone 2. For WR5a, reservoir Res3 has cumulative capacities at the top of inactive pool, active pool zone 2, and zone 1 of 150 ac-ft, 300 ac-ft, and 300 ac-ft. Thus, zone 1 in Res3 has zero capacity. Res4 must be half empty before water is taken from Res3. Likewise, water is not withdrawn from Res3 for WR5 if the storage content of Res3 falls below 150 ac-ft.

CP5 is located in a different river basin than the other control points. Water withdrawn from Res3 and CP4 is conveyed by pipeline (or some means other than the gravity flow in river channels) to the WR5a diversion site at CP5. Consequently, a negative one is entered in field 6 of the *OR* record. A negative integer in this field has the effect of acting as a switch to allow a reservoir to release to a diversion with a control point location which is not downstream of the reservoir. Field 11 of the *WS* record is also flagged with a negative integer indicating that the WR5a releases from Res3 do not pass through the hydroelectric power plant associated with water right WR7.

Water Right WR6. - WR6 diverts 120 ac-ft/yr at CP4 from available stream flow and Res3 storage. Since WR6 is not permitted to refill storage, a type 2 right is specified.

Water Right WR7. - WR7 generates hydroelectric power and refills storage in Res3. With a POWFCT value of 1.0237, the energy units are kilowatt-hours. The permitted firm energy is a constant 12,000 kW-hr. The cumulative total storage capacity and inactive pool (bottom of power pool) capacity are 300 ac-ft and 30 ac-ft respectively. The tailwater elevation is 5.0 feet, and the plant efficiency is 85%. All flows through control point CP4 can be diverted through the hydroelectric turbines except for the lakeside withdrawals from Res3 for WR5. WR7 is a type 5 right with Res3 as the primary (and only) reservoir.

Res3 storage versus elevation data, used to compute the head term of the power equation, are provided on *PV* and *PE* records. The elevation is assumed to vary linearly from zero to 100 feet as storage varies from zero to 300 ac-ft.

Water Right WR8. - WR8 is a type 3 diversion right with the permitted diversion amount being supplied only by reservoirs Res1, Res2, and Res3 without appropriating stream flows at CP6. The diversion target is a function of month of the year (*WR* record field 4 and *UC* records). The permitted diversion is zero during the months from September through April (*UC* records). During the remaining four months, the permitted diversion is ac-ft/month.

## WRAP-SIM Input File for Example 6

```

T1 WRAP-SIM Input File Exam6.DAT
T2 Example 6 from Appendix B of Reference Manual
**
**                               Fixed-Width Fields and Columns
**      2 !      3 !      4 !      5 !      6 !      7 !      8 !      9 !      10 !      11 !      12 !
** 3-8 !  9-16 ! 17-24 ! 25-32 ! 33-40 ! 41-48 ! 49-56 ! 57-64 ! 65-72 ! 73-80 ! 81-88 !
**
JD      2      1997      1      -1      -1
JO      4
XL                               1.0237
RO      1      RES3
**
** Monthly Use Factors
**
UC  MUN      0.06      0.06      0.07      0.07      0.08      0.10
UC                               0.13      0.12      0.09      0.08      0.08      0.06
UC  IRRIG     0         0         0         0         0.25      0.25
UC                               0.25      0.25      0         0         0         0
**
** Control Point Records
**
CP  CP1      CP3
CP  CP2      CP3      0.08333
CP  CP3      CP4                               NONE
CP  CP4      CP6                               CP1
CP  CP5      OUT      0.811                    CP1
CP  CP6      OUT                               NONE
**
**      ! 1      ! 2      ! 3      ! 4      ! 5      ! 6      ! 7      ! 8
** 34567890123456789012345678901234567890123456789012345678901234567890
**      !      !      !      !      !      !      !      !
** Water Rights and Associated Reservoirs
**
** Water Right IF2 -----
IF  CP6      240      191803      IF2
** Water Right IF1 -----
IF  CP3      120      191805      IF1
** Water Right WR1 -----
WR  CP1      360.      192602      1      .2      WR1
WS  RES1     200.      .1      1.      0.      10.
** Water Right WR2 -----
WR  CP2      60.      IRRIG 193908      1      .2      WR2
WS  RES2     50.      .1      1.      0.      25.
** Water Right WR3 -----
WR  CP2      180.      196506      1      .2      WR3
WS  RES2     250.      .1      1.      0.      25.
** Water Right WR4 -----
WR  CP3      720.      MUN 195207      2      0.4      WR4
WS  RES2     250.      25.
OR   125.      1      1
WS  RES1     200.      10.
OR   200.      0      1
** Water Rights WR5a and WR5b -----
WR  CP5      0.      196213      1      WR5b
WS  RES4     200.      -1      100.
WR  CP5      600.      196212      2      WR5a
WS  RES4     200.      -1
OR   100.      1      1      -1
WS  RES3     300.      .1      1.      0.      150.
OR   CP4     300.      1      1      -1
** Water Right WR6 -----
WR  CP4      120.      195704      2      WR6
WS  RES3     300.      .1      1.      0.      30.
** Water Right WR7 -----
WR  CP4     12000.      197801      5      WR7
WS  RES3     300.      30.
HP   0.85      5.

```

## Continuation of WRAP-SIM Input File for Example 6

```

** Water Right WR8 -----
WR CP6 400. IRRIG 197412 3 2 WR8
WS RES2 250. 25.
OR 125. 1 1
WS RES1 200. 10.
OR 200. 0 1
WS RES3 300. .1 1. 0. 30.
OR 165. 1 1
**
** Storage versus Area Table for Reservoir RES4
**
SV RES4 0. 200.
SA 0. 20.
**
** Storage versus Elevation Table for Reservoir RES3
**
PV RES3 0. 300.
PE 0. 100.
**
ED
**
** Monthly Naturalized Streamflow
**
IN CP1 1997 60 60 60 60 60 60 10 10 10 10 10 10
IN CP1 1998 60 60 60 300 300 300 10 10 10 10 10 10
IN CP2 1997 20 20 20 20 20 20 0 0 0 0 0 0
IN CP2 1998 20 20 20 100 100 100 0 0 0 0 0 0
IN CP3 1997 120 120 120 100 100 100 30 30 30 30 30 30
IN CP3 1998 120 120 120 500 500 500 30 30 30 30 30 30
IN CP4 1997 120 120 120 120 120 120 40 40 40 40 40 40
IN CP4 1998 120 120 120 600 600 600 40 40 40 40 40 40
IN CP5 1997 74 74 74 12.33 12.33 12.33 12.33 12.33 12.33 92.5 92.5 92.5
IN CP5 1998 74 74 74 61.67 61.67 61.67 12.33 12.33 12.33 92.5 92.5 92.5
IN CP6 1997 150 150 150 180 180 180 50 50 50 50 50 50
IN CP6 1998 150 150 150 900 900 900 50 50 50 50 50 50
**
** Monthly Net Evaporation-Precipitation Depths
**
EV CP1 1997 .5 .5 .5 .5 .5 .5 .5 .5 .5 .5 .5 .5
EV CP1 1998 .5 .5 .5 .5 .5 .5 .5 .5 .5 .5 .5 .5
EV CP2 1997 6. 6. 6. 6. 6. 6. 6. 6. 6. 6. 6. 6.
EV CP2 1998 6. 6. 6. 6. 6. 6. 6. 6. 6. 6. 6. 6.

```

## TABLES Input File for Example 6

```

COMM TABLES Input File Tab6.TIN
COMM Example 6
2REL
2REL 2 1
IDEN RES3
2FRE 1
2FRE 2
2FRE 3
2FRE 4 0 4
IDEN CP1 CP2 CP4 CP5
2REG 1 1 1
2UNA 1 1 0
ENDF

```

## TABLES Output File for Example 6

### RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET	MEAN	*RELIABILITY*		PERCENTAGE OF MONTHS								PERCENTAGE OF YEARS							
	DIVERSION	SHORTAGE	PERIOD	VOLUME	WITH DIVERSIONS EQUALING OR EXCEEDING								PERCENTAGE OF TARGET DIVERSION AMOUNT							
	(AC-FT/YR)	(AC-FT/YR)	(%)	(%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%		
CP1	360.0	82.00	66.67	77.22	66.7	66.7	66.7	66.7	66.7	100.0	100.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0		
CP2	240.0	67.83	58.33	71.74	58.3	62.5	62.5	62.5	66.7	66.7	66.7	0.0	0.0	0.0	0.0	0.0	100.0	100.0		
CP3	720.0	165.52	62.50	77.01	62.5	66.7	66.7	66.7	70.8	79.2	100.0	0.0	0.0	0.0	0.0	50.0	100.0	100.0		
CP4	120.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0		
CP5	600.0	28.98	91.67	95.17	91.7	91.7	91.7	91.7	95.8	95.8	100.0	50.0	50.0	50.0	100.0	100.0	100.0	100.0		
CP6	400.0	8.02	87.50	97.99	87.5	87.5	87.5	100.0	100.0	100.0	100.0	50.0	50.0	100.0	100.0	100.0	100.0	100.0		
Total	2440.0	352.36		85.56																

### RELIABILITY SUMMARY FOR SELECTED HYDROELECTRIC POWER PROJECTS

NAME	ENERGY	MEAN	*RELIABILITY*		PERCENTAGE OF MONTHS								PERCENTAGE OF YEARS							
	TARGET	SHORTAGE	PERIOD	AMOUNT	WITH ENERGY GENERATION EQUALING OR EXCEEDING								PERCENTAGE OF TARGET							
	(%)	(%)	(%)	(%)	100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%	1%		
RES3	12000.0	3093.55	70.83	74.22	70.8	70.8	70.8	70.8	70.8	75.0	100.0	0.0	0.0	0.0	0.0	50.0	100.0	100.0		
Total	12000.0	3093.55		74.22																

### FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP1	65.0	94.	10.0	10.0	10.0	10.0	10.0	10.0	10.	60.	60.	60.	300.	300.
CP2	20.0	32.	0.0	0.0	0.0	0.0	0.0	0.0	0.	20.	20.	20.	100.	100.
CP3	120.0	152.	30.0	30.0	30.0	30.0	30.0	30.0	30.	100.	108.	120.	500.	500.
CP4	140.0	182.	40.0	40.0	40.0	40.0	40.0	40.0	40.	120.	120.	120.	600.	600.
CP5	43.8	28.	10.0	10.0	10.0	10.0	10.0	10.0	50.	60.	60.	75.	75.	75.
CP6	197.5	276.	50.0	50.0	50.0	50.0	50.0	50.0	50.	150.	150.	180.	900.	900.

### FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP1	45.1	74.	0.0	0.0	0.0	0.0	0.0	0.0	12.	20.	22.	65.	207.	260.
CP2	10.1	20.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	14.	58.	67.
CP3	51.5	88.	10.0	10.0	10.0	10.0	10.0	10.0	13.	13.	21.	30.	255.	314.
CP4	59.4	115.	0.0	0.0	0.0	0.0	0.0	0.0	0.	2.	10.	100.	282.	408.
CP5	0.0	0.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	0.	0.
CP6	95.9	169.	10.0	10.0	10.0	10.0	10.0	23.3	33.	48.	49.	60.	492.	608.



FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP1	22.4	73.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.	158.	260.
CP2	0.1	1.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	3.
CP3	25.5	84.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.	176.	304.
CP4	26.7	86.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.	189.	308.
CP5	0.0	0.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.
CP6	78.0	168.	0.0	0.0	0.0	0.0	0.0	3.3	13.	28.	29.	40.	472.	588.

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

CONTROL POINT	STANDARD		PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP1	89.	86.	10.	10.	10.	10.	10.	10.	23.	55.	121.	200.	200.	200.
CP2	96.	87.	20.	21.	21.	22.	22.	24.	27.	53.	97.	179.	236.	243.
CP4	168.	110.	30.	30.	30.	30.	30.	30.	160.	197.	213.	300.	300.	300.
CP5	62.	33.	0.	0.	0.	5.	23.	30.	68.	72.	76.	84.	108.	114.
Total	415.	287.	64.	69.	75.	89.	101.	193.	264.	275.	514.	756.	844.	848.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	20.	20.	20.	20.	36.	50.	75.	24.	0.	0.	0.	0.	265.
1998	7.	7.	14.	128.	260.	260.	75.	65.	0.	0.	0.	0.	817.
MEAN	14.	14.	17.	74.	148.	155.	75.	45.	0.	0.	0.	0.	541.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	0.	0.	0.	14.	19.	67.	0.	11.	0.	0.	0.	0.	112.
1998	0.	0.	0.	0.	0.	0.	17.	62.	52.	0.	0.	0.	131.
MEAN	0.	0.	0.	7.	10.	34.	8.	37.	26.	0.	0.	0.	122.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	26.	26.	19.	13.	30.	78.	13.	10.	10.	10.	10.	10.	253.
1998	13.	13.	13.	187.	314.	300.	30.	73.	10.	10.	10.	10.	983.
MEAN	19.	19.	16.	100.	172.	189.	21.	42.	10.	10.	10.	10.	618.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	6.	6.	2.	16.	100.	100.	100.	84.	0.	0.	0.	0.	414.
1998	0.	0.	0.	0.	408.	404.	100.	100.	0.	0.	0.	0.	1012.
MEAN	3.	3.	1.	8.	254.	252.	100.	92.	0.	0.	0.	0.	713.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP5

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1998	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP6

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	48.	48.	44.	88.	60.	60.	10.	10.	53.	23.	23.	23.	491.
1998	49.	49.	52.	323.	608.	604.	10.	10.	10.	30.	32.	34.	1810.
MEAN	48.	48.	48.	206.	334.	332.	10.	10.	32.	26.	27.	29.	1151.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	6.	6.	2.	3.	0.	0.	0.	0.	0.	0.	0.	0.	17.
1998	0.	0.	0.	0.	260.	260.	0.	0.	0.	0.	0.	0.	520.
MEAN	3.	3.	1.	2.	130.	130.	0.	0.	0.	0.	0.	0.	268.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.	0.	0.	3.
1998	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	0.	0.	0.	2.	0.	0.	0.	0.	0.	0.	0.	0.	2.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	6.	6.	2.	3.	0.	0.	0.	0.	0.	0.	0.	0.	17.
1998	0.	0.	0.	0.	304.	290.	0.	0.	0.	0.	0.	0.	594.
MEAN	3.	3.	1.	2.	152.	145.	0.	0.	0.	0.	0.	0.	306.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	6.	6.	2.	16.	0.	0.	0.	0.	0.	0.	0.	0.	30.
1998	0.	0.	0.	0.	308.	304.	0.	0.	0.	0.	0.	0.	612.
MEAN	3.	3.	1.	8.	154.	152.	0.	0.	0.	0.	0.	0.	321.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP5

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1998	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

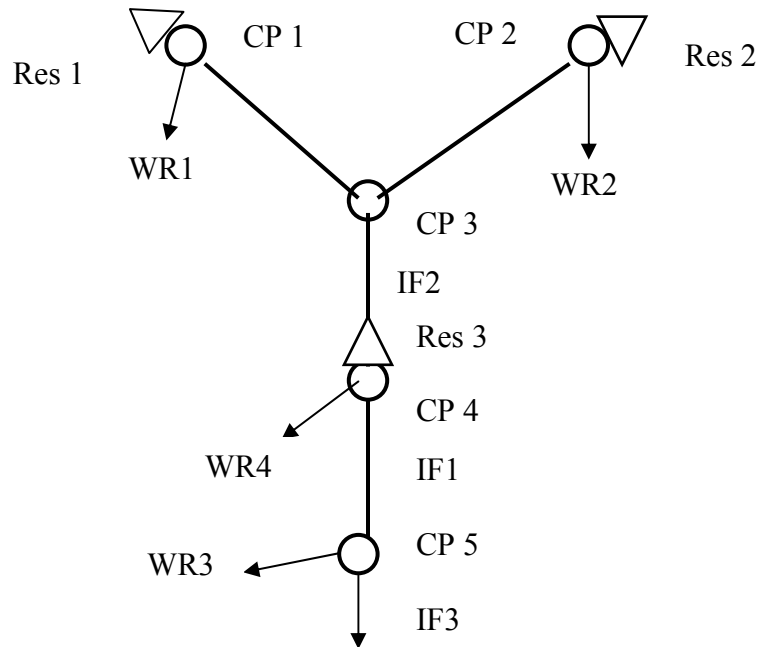
UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP6

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1997	28.	28.	24.	68.	40.	40.	0.	0.	33.	3.	3.	3.	271.
1998	29.	29.	32.	303.	588.	584.	0.	0.	0.	10.	12.	14.	1600.
MEAN	28.	28.	28.	186.	314.	312.	0.	0.	17.	6.	7.	9.	936.

		REG CP1	REG CP2	REG CP3	REG CP4	REG CP5	REG CP6	UNA CP1	UNA CP2	UNA CP3	UNA CP4	UNA CP5	UNA CP6
1997	1	20.00	0.00	25.80	5.98	0.00	48.08	5.98	0.00	5.98	5.98	0.00	28.08
1997	2	20.00	0.00	25.80	5.98	0.00	48.08	5.98	0.00	5.98	5.98	0.00	28.08
1997	3	20.00	0.00	18.60	1.66	0.00	43.76	1.66	0.00	1.66	1.66	0.00	23.76
1997	4	20.00	14.40	13.00	16.06	0.00	88.16	3.00	3.00	3.00	16.06	0.00	68.16
1997	5	36.10	19.13	29.63	100.00	0.00	60.00	0.00	0.00	0.00	0.00	0.00	40.00
1997	6	50.50	66.96	77.46	100.00	0.00	60.00	0.00	0.00	0.00	0.00	0.00	40.00
1997	7	74.60	0.00	13.00	100.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	8	23.80	11.32	10.00	83.96	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	9	0.00	0.00	10.00	0.00	0.00	53.36	0.00	0.00	0.00	0.00	0.00	33.36
1997	10	0.00	0.00	10.00	0.00	0.00	23.26	0.00	0.00	0.00	0.00	0.00	3.26
1997	11	0.00	0.00	10.00	0.00	0.00	23.26	0.00	0.00	0.00	0.00	0.00	3.26
1997	12	0.00	0.00	10.00	0.00	0.00	23.26	0.00	0.00	0.00	0.00	0.00	3.26
1998	1	7.20	0.00	12.87	0.00	0.00	48.65	0.00	0.00	0.00	0.00	0.00	28.65
1998	2	7.20	0.00	13.00	0.00	0.00	48.78	0.00	0.00	0.00	0.00	0.00	28.78
1998	3	14.40	0.00	13.00	0.00	0.00	51.66	0.00	0.00	0.00	0.00	0.00	31.66
1998	4	128.48	0.00	187.08	0.00	0.00	323.31	0.00	0.00	0.00	0.00	0.00	303.31
1998	5	260.00	0.00	314.40	408.33	0.00	608.33	260.00	0.00	304.40	308.33	0.00	588.33
1998	6	260.00	0.00	300.00	403.80	0.00	603.80	260.00	0.00	290.00	303.80	0.00	583.80
1998	7	74.60	16.63	29.63	100.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	8	65.25	62.42	73.27	100.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	9	0.00	52.43	10.00	0.00	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	10	0.00	0.00	10.00	0.00	0.00	29.74	0.00	0.00	0.00	0.00	0.00	9.74
1998	11	0.00	0.00	10.00	0.00	0.00	31.59	0.00	0.00	0.00	0.00	0.00	11.59
1998	12	0.00	0.00	10.00	0.00	0.00	34.06	0.00	0.00	0.00	0.00	0.00	14.06

### Example 7 Featuring Target Options *TO* and Target Series *TS* records

The purpose of Example 7 is to illustrate the use of target options *TO* and target series *TS* records in specifying instream flow and diversion targets. The *TABLES* output file is developed in a columnar format that facilitates transporting the simulation results to a spreadsheet program for plotting or other data manipulations. A schematic of the system is provided below and each water right is described.



**System Schematic for Example 7**

Instream Flow Right *IF 1*. The instream flow target at control point CP4 is set equal to the incremental naturalized flows entering the river above CP4 and below CP1 and CP2 constrained by lower and upper bounds. *TO* records are used to subtract (*NFACT*= -1) the naturalized (*TOFLOW*=1) flows at CP1 and CP2 from those at CP4. Instream flow right *IF1* has another feature that limits the target to the range from 3 to 68 ac-ft/month (*TO* record fields 7 and 8). If the incremental (CP4 - CP1 - CP2) flow is below 3 ac-ft, the target is set at 3 ac-ft. Likewise, if the CP4-CP1-CP2 naturalized flow is above 68 ac-ft, the target is set at 68 ac-ft.

Instream Flow Right *IF 2*. An instream flow requirement at CP3 varies between the two years of the simulation period-of-analysis. A *TS* record is entered for each year.

Instream Flow Right *IF 3*. The instream flow target at CP5 consists of the flow values entered on the *TS* record added to the minimum of: (a) 100 ac-ft/month or (b) the naturalized stream flow at CP5.

Water Rights *WR 1*, *WR 2*, and *WR 4*. These are standard type 1 rights with both a diversion and reservoir storage.

Water Right WR 3. WR3 is a run-of-river diversion right at control point CP5. The monthly diversion target is the lesser of 400 ac-ft or the naturalized stream flow at CP5.

Water Rights WR 5 and WR 7. WR5 diverts water from reservoir Res 3 at CP4 and transports it to CP1 for refilling by WR7 of storage in Res 1. The WR5 diversion target is computed as the minimum of the drawdown in Res 1 and the regulated flow at CP1. This models a situation in which Res 1 and Res 3 are operated as a system with the operating rules being based on maintaining as much storage in Res 1 as possible even though Res 3 has the more senior water right permit. There is actually no pipeline/pumping facility. Flows are allocated in accordance with the water rights priority system except WR5 and WR7 are added at the end of the priority loop to reallocate releases from Res 1 back to Res 1 from Res 3. Thus, the WR5 dummy diversion is limited to the regulated flows below Res 1 (representing downstream releases) and the storage drawdown in Res 1. WR7 uses the water diverted to CP1 to refill Res 1.

Water Rights WR 6 and WR 8. WR6 diverts water from reservoir Res 3 at CP4 and transports it to CP2 for refilling by WR8 of storage in Res 2. This models a situation in which Res 2 and Res 3 are operated as a system with the operating rules being based on maintaining as much storage in Res 2 as possible even though Res 3 has the more senior water right permit. There is a pipeline/pumping facility so flows are not limited to the regulated flows below Res 2 as done for WR 5 above.

### TABLES Input File for Example 7

```

COMM TABLES Input File Exam7.TIN
COMM Example 7
2NAT 0 1 1 0 0
2REG 0 1 0 0 0
2STO 0 1 1 2 3
IDEN Res 1 Res 2 Res 3
2DIV 0 1 1 1 3
IDEN WR3 WR5 WR6
2SHT 0 1 0 1 -3
ENDF

```

### WRAP-SIM FLO File for Example 7

```

** WRAP-SIM Input File Exam7.FLO
** Example 7 from Appendix B of Reference Manual
**
** Naturalized Streamflow
**
IN CP1 2006 60 60 60 120 120 120 10 10 10 10 10 10
IN CP2 2006 20 20 20 90 90 90 0 0 0 0 0 0
IN CP3 2006 120 120 120 240 240 240 30 30 30 30 30 30
IN CP4 2006 120 120 120 460 460 460 40 40 40 40 40 40
IN CP5 2006 150 150 150 680 680 680 50 50 50 50 50 50
IN CP1 2007 60 60 60 300 300 300 10 10 10 10 10 10
IN CP2 2007 20 20 20 100 100 100 0 0 0 0 0 0
IN CP3 2007 120 120 120 500 500 500 30 30 30 30 30 30
IN CP4 2007 120 120 120 600 600 600 40 40 40 40 40 40
IN CP5 2007 150 150 150 900 900 900 50 50 50 50 50 50

```

## WRAP-SIM DAT File for Example 7

```

T1 WRAP-SIM Input File Exam7.DAT
T2 Example 7 from Appendix B of Reference Manual
**
JD      2      2006      1      -1      -1
JO      -1
RO      3      Res 1      Res 2      Res 3
**
CP      CP1      CP3                        NONE
CP      CP2      CP3                        NONE
CP      CP3      CP4                        NONE
CP      CP4      CP5                        NONE
CP      CP5      OUT                       NONE
**
**!  2 !    3 !    4 !    5 !    6 !    7 !    8 !    9 !   10 !   11 !   12 !   13 !   14 !
**! 3-8 !  9-16 ! 17-24 ! 25-32 ! 33-40 ! 41-48 ! 49-56 ! 57-64 ! 65-72 ! 73-80 ! 81-88 ! 89-96 ! 97-104!
**
** Water Right IF1 -----
IF      CP4                        1900      2                        IF1
TO      1                        CP4                        CONT
TS      1      - 1.0      ADD                        CP1                        CONT
TO      1      - 1.0      ADD      3.0      68.0      CP2
** Water Right IF2 -----
IF      CP3                        1901      2                        IF2
TS      2006      20.      20.      20.      20.      20.      20.      20.      20.      20.      20.      20.
TS      2007      15.      15.      15.      15.      15.      15.      15.      15.      15.      15.      15.
** Water Right IF3 -----
IF      CP5      1200.      1902      2                        IF3
TO      1                        MIN                        CP5
TS      ADD20062007      25.      25.      25.      30.      30.      30.      0.      0.      0.      40.      40.      40.
** Water Right WR1 -----
WR      CP1      2400.      1985                        WR1
WS      Res 1      5000.      .1      1.
** Water Right WR2 -----
WR      CP2      2400.      1978                        WR2
WS      Res 2      5000.      .1      1.
** Water Right WR3 -----
WR      CP5      4800.      1903                        WR3
TO      1                        MIN                        CP5
** Water Right WR4 -----
WR      CP4      3600.      1950                        WR4
WS      Res 3      8000.      .1      1.
** Water Right WR5 -----
WR      CP4      0.      2000      3      1.0      CP1      WR5
WS      Res 3      8000.      .1      1.
TO      5                        Res 1                        CONT
TO      2                        MIN                        CP1
** Water Right WR6 -----
WR      CP4      0.      2000      3      1.0      CP2      WR6
WS      Res 3      8000.      .1      1.
TO      5                        Res 2
** Water Right WR7 -----
WR      CP1      0.      2001                        WR7
WS      Res 1      5000.      .1      1.
** Water Right WR8 -----
WR      CP2      0.      2001                        WR8
WS      Res 2      5000.      .1      1.
**
**
**!  2 !    3 !    4 !    5 !    6 !    7 !    8 !    9 !   10 !   11 !   12 !   13 !   14 !
**! 3-8 !  9-16 ! 17-24 ! 25-32 ! 33-40 ! 41-48 ! 49-56 ! 57-64 ! 65-72 ! 73-80 ! 81-88 ! 89-96 ! 97-104!
**
ED

```

**TABLES Output File for Example 7**

		NAT	NAT	NAT	NAT	NAT	REG	REG	REG	REG	REG
		CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5
2006	1	60.00	20.00	120.00	120.00	150.00	0.00	80.00	120.00	120.00	125.00
2006	2	60.00	20.00	120.00	120.00	150.00	0.00	80.00	120.00	120.00	125.00
2006	3	60.00	20.00	120.00	120.00	150.00	0.00	80.00	120.00	120.00	125.00
2006	4	120.00	90.00	240.00	460.00	680.00	0.00	210.00	240.00	310.00	130.00
2006	5	120.00	90.00	240.00	460.00	680.00	0.00	210.00	240.00	310.00	130.00
2006	6	120.00	90.00	240.00	460.00	680.00	0.00	210.00	240.00	310.00	130.00
2006	7	10.00	0.00	30.00	40.00	50.00	0.00	10.00	30.00	40.00	50.00
2006	8	10.00	0.00	30.00	40.00	50.00	0.00	10.00	30.00	40.00	50.00
2006	9	10.00	0.00	30.00	40.00	50.00	0.00	10.00	30.00	40.00	50.00
2006	10	10.00	0.00	30.00	40.00	50.00	0.00	50.00	70.00	80.00	90.00
2006	11	10.00	0.00	30.00	40.00	50.00	0.00	50.00	70.00	80.00	90.00
2006	12	10.00	0.00	30.00	40.00	50.00	0.00	50.00	70.00	80.00	90.00
2007	1	60.00	20.00	120.00	120.00	150.00	0.00	80.00	120.00	120.00	125.00
2007	2	60.00	20.00	120.00	120.00	150.00	0.00	80.00	120.00	120.00	125.00
2007	3	60.00	20.00	120.00	120.00	150.00	60.00	20.00	120.00	120.00	125.00
2007	4	300.00	100.00	500.00	600.00	900.00	300.00	100.00	500.00	230.00	130.00
2007	5	300.00	100.00	500.00	600.00	900.00	300.00	100.00	500.00	230.00	130.00
2007	6	300.00	100.00	500.00	600.00	900.00	300.00	100.00	500.00	230.00	130.00
2007	7	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00
2007	8	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00
2007	9	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00
2007	10	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00
2007	11	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00
2007	12	10.00	0.00	30.00	40.00	50.00	10.00	0.00	30.00	40.00	50.00

		STO	STO	STO	DIV	DIV	DIV	SHT	SHT	SHT
		Res 1	Res 2	Res 3	WR3	WR5	WR6	WR3	WR5	WR6
2006	1	4920.00	4940.00	7440.00	25.00	60.00	200.00	125.00	0.00	0.00
2006	2	4840.00	4940.00	6820.00	25.00	60.00	260.00	125.00	0.00	0.00
2006	3	4760.00	4940.00	6200.00	25.00	60.00	260.00	125.00	0.00	0.00
2006	4	4800.00	4880.00	5670.00	400.00	120.00	260.00	0.00	0.00	0.00
2006	5	4840.00	4880.00	5080.00	400.00	120.00	320.00	0.00	0.00	0.00
2006	6	4880.00	4880.00	4490.00	400.00	120.00	320.00	0.00	0.00	0.00
2006	7	4700.00	4990.00	3860.00	0.00	10.00	320.00	50.00	0.00	0.00
2006	8	4520.00	4990.00	3340.00	0.00	10.00	210.00	50.00	0.00	0.00
2006	9	4340.00	4990.00	2820.00	0.00	10.00	210.00	50.00	0.00	0.00
2006	10	4160.00	4950.00	2300.00	0.00	10.00	210.00	50.00	0.00	0.00
2006	11	3980.00	4950.00	1740.00	0.00	10.00	250.00	50.00	0.00	0.00
2006	12	3800.00	4950.00	1180.00	0.00	10.00	250.00	50.00	0.00	0.00
2007	1	3720.00	4940.00	570.00	25.00	60.00	250.00	125.00	0.00	0.00
2007	2	3640.00	4890.00	0.00	25.00	60.00	210.00	125.00	0.00	50.00
2007	3	3440.00	4690.00	0.00	25.00	0.00	0.00	125.00	60.00	310.00
2007	4	3310.00	4490.00	0.00	400.00	70.00	0.00	0.00	230.00	510.00
2007	5	3180.00	4290.00	0.00	400.00	70.00	0.00	0.00	230.00	710.00
2007	6	3050.00	4090.00	0.00	400.00	70.00	0.00	0.00	230.00	910.00
2007	7	2850.00	3890.00	0.00	0.00	0.00	0.00	50.00	10.00	1110.00
2007	8	2650.00	3690.00	0.00	0.00	0.00	0.00	50.00	10.00	1310.00
2007	9	2450.00	3490.00	0.00	0.00	0.00	0.00	50.00	10.00	1510.00
2007	10	2250.00	3290.00	0.00	0.00	0.00	0.00	50.00	10.00	1710.00
2007	11	2050.00	3090.00	0.00	0.00	0.00	0.00	50.00	10.00	1910.00
2007	12	1850.00	2890.00	0.00	0.00	0.00	0.00	50.00	10.00	2110.00

### Example 8 with Multiple-Owner Reservoir

The purpose of Example 8 is to illustrate the use of evaporation allocation *EA*, evaporation allocation factors *EF*, and stream flow availability allocation factors *AF* records to model a reservoir owned by multiple entities. Models are formulated with and without use of *EA*, *EF*, and *AF* records for comparison.

Three water supply entities share the conservation pool of a federal reservoir project. Entities 1 and 2 have each contracted for 40 percent of the conservation storage capacity. Entity 3 has contracted for the remaining 20 percent of the storage capacity. Water supply contracts were executed at project construction and the water right permits have the same priority date. If the three entities each withdraw water from the reservoir in proportion to their storage capacity, the allocation is simple as illustrated by the following *SIM* input and *TABLES* output files.

```
T1 WRAP-SIM Input File Exam8B.DAT
T2 Example 8 from Appendix B of Reference Manual
T3 Single Reservoir for Comparison
JD  2  1990      1    -1    -1
JO   3
CP  CP1
WR  CP1 300000          1          WR-1B
WS Res-A 500000
SV Res-A   0 100000 200000 400000 500000
SA       0  10000  20000  40000  50000
ED
IN  CP1  1990 100000 100000 100000   0   0   0   0   0   0 10000 10000 10000
EV  CP1  1990   0.2   0.2   0.2   0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
IN  CP1  1991 200000 200000 200000 500000 500000 500000   0   0   0 10000 20000 50000
EV  CP1  1991   0.5   0.5   0.5   0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5
```

#### MONTHLY SUMMARY TABLE FOR WATER RIGHT WR-1B

YEAR	MONTH	AVAILABLE STREAMFLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	SYSTEM RELEASES (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	SHORTAGE (AC-FT)
1990	1	100000.0	35000.0	500000.0	10000.0	0.0	25000.0	25000.0	0.0
1990	2	100000.0	35000.0	500000.0	10000.0	0.0	25000.0	25000.0	0.0
1990	3	100000.0	35000.0	500000.0	10000.0	0.0	25000.0	25000.0	0.0
1990	4	0.0	0.0	465346.5	9653.5	0.0	25000.0	25000.0	0.0
1990	5	0.0	0.0	431379.3	8967.3	0.0	25000.0	25000.0	0.0
1990	6	0.0	0.0	398084.6	8294.6	0.0	25000.0	25000.0	0.0
1990	7	0.0	0.0	365449.3	7635.3	0.0	25000.0	25000.0	0.0
1990	8	0.0	0.0	333460.2	6989.1	0.0	25000.0	25000.0	0.0
1990	9	0.0	0.0	302104.5	6355.6	0.0	25000.0	25000.0	0.0
1990	10	10000.0	10000.0	281270.8	5833.8	0.0	25000.0	25000.0	0.0
1990	11	10000.0	10000.0	260849.6	5421.2	0.0	25000.0	25000.0	0.0
1990	12	10000.0	10000.0	240832.8	5016.8	0.0	25000.0	25000.0	0.0
1991	1	20000.0	20000.0	224206.8	11626.0	0.0	25000.0	25000.0	0.0
1991	2	20000.0	20000.0	208391.8	10815.0	0.0	25000.0	25000.0	0.0
1991	3	20000.0	20000.0	193348.3	10043.5	0.0	25000.0	25000.0	0.0
1991	4	500000.0	348985.4	500000.0	17333.7	0.0	25000.0	25000.0	0.0
1991	5	500000.0	50000.0	500000.0	25000.0	0.0	25000.0	25000.0	0.0
1991	6	500000.0	50000.0	500000.0	25000.0	0.0	25000.0	25000.0	0.0
1991	7	0.0	0.0	451219.5	23780.5	0.0	25000.0	25000.0	0.0
1991	8	0.0	0.0	404818.5	21400.9	0.0	25000.0	25000.0	0.0
1991	9	0.0	0.0	360681.0	19137.5	0.0	25000.0	25000.0	0.0
1991	10	10000.0	10000.0	328452.7	17228.3	0.0	25000.0	25000.0	0.0
1991	11	20000.0	20000.0	307552.6	15900.1	0.0	25000.0	25000.0	0.0
1991	12	50000.0	50000.0	316940.2	15612.3	0.0	25000.0	25000.0	0.0
MEAN		82083.3	30166.1	369766.2	12793.5	0.0	25000.0	25000.0	0.0



In the model on the preceding page, the three entities sharing the reservoir are simply treated as the one water right WR-1B. If the 25,000 acre-feet/month diversion target is divided between them in proportion to their storage capacity, their allocations are 10,000 ac-ft/month, 10,000 ac-ft/month, and 5,000 ac-ft/month. Diversions and shortages are allocated in the same proportion. However, adoption of a modeling strategy based on three component reservoirs and *EA*, *EF*, and *AF* records would be motivated by the complexity of the three entities having different diversion needs. If an entity diverts little water relative to its ownership of storage capacity, it should have more water in storage to provide protection against future drought conditions. An accounting system is needed to keep track of the amount of water that each of the three water supply entities has in storage.

The following model formulation illustrates the component reservoir strategy described in Chapter 4 for accounting for water in a reservoir shared by multiple owners. The storage and diversions allocated to each of the three entities are tracked by assigning each a "*computational*" component reservoir representing its share of the actual single reservoir. The *EA* and *EF* records are used to allocate the actual total net evaporation-precipitation between the three component reservoirs. The approach presented on the preceding page would actually be adopted for the simple case in which water supply diversions occur in the same proportion as storage capacity, and the three entities share the same water right priority. However, this simple example provides an opportunity to explore simulation features by comparing results for the model presented on the preceding page with the results for the model on the next page.

The *AF* record would not be used if the three entities had different water right priorities. However, since they share the same priority, the *AF* record factors provide a scheme to allocate available stream flow to the three rights in the priority-based simulation sequence. The available stream flow is allocated in proportion to storage capacity. WR-1, which is considered first in the water right computational loop priority sequence, is restricted to appropriate no more than 40 percent of the available stream flow. WR-2 which is considered next in the priority sequence is restricted to no more than two-thirds of the remaining available stream flow. WR-3 is considered last in the computational sequence and has access to all of the remaining available stream flow.

Since there are no diversion shortages, the resulting control point summary table is identical for either the model presented below or the model presented on the presenting page. The stream flow depletion, diversion, storage, and evaporation volumes for WR-1, WR-2, and WR-3 in the model on the following pages sum to the values for WR-1B of the model on the preceding page.

The allocation of evaporation between WR-1, WR-2, and WR-3 is approximate and does not result in perfectly matching evaporation volumes in proportion to storage capacity for the following reason. Evaporation and end-of-month storage volumes are computed in an iterative algorithm since each depends upon the other. When the computations are performed for WR-1, the other two water rights have not yet been considered, and thus the final end-of-month storage is not yet known. Likewise, computations for WR-2 are performed prior to consideration of WR-3. The correct total evaporation volume is maintained because the evaporation allocated to WR-3 is computed as the correct total volume minus the amounts allocated to WR-1 and WR-2.

## WRAP-SIM Input File for Example 8

```

T1 WRAP-SIM Input File Exam8.DAT
T2 Example 8 from Appendix B of Reference Manual
T3 Illustrating Evaporation and Available Flow Allocation EA, EF, and AF Records
**
** The allocation of storage capacity, net evaporation-precipitation, and available streamflow is illustrated
** with this simple data set. Res-A, Res-B, and Res-C are "computational" component reservoirs representing a
** single actual reservoir owned/shared by three water supply entities. The three component reservoirs have a
** common storage-area relationship which is provided as SV/SA records assigned to Res-A.
**
JD      2      1990      1      -1      -1
JO      3
**
CP      CP1
**      1          2          3          4          5          6          7
**3456789012345678901234567890123456789012345678901234567890123456789012
**      !          !          !          !          !          !          !          !
WR      CP1      120000          1          WR-1
WS      Res-A    200000          1
**
WR      CP1      120000          2          WR-2
WS      Res-B    200000          1          -1
**
WR      CP1      60000          3          WR-3
WS      Res-C    100000          1          -1
**
SV      Res-A      0  100000  200000  400000  500000
SA      0  10000  20000  40000  50000
**
** 40%, 40%, and 20% of both the net evaporation and available streamflow are
** allocated to component reservoirs Res-A, Res-B, and Res-C, respectively.
**
EA      1          3      Res-A      Res-B      Res-C
EF      0          0          0.4      0.4
AF      0          0          0.40.666667      1.0
**
ED
**
IN      CP1      1990  100000  100000  100000      0      0      0      0      0      0      10000  10000  10000
EV      CP1      1990      0.2      0.2      0.2      0.2      0.2      0.2      0.2      0.2      0.2      0.2      0.2
**
IN      CP1      1991  20000  20000  20000  500000  500000  500000      0      0      0      10000  20000  50000
EV      CP1      1991      0.5      0.5      0.5      0.5      0.5      0.5      0.5      0.5      0.5      0.5      0.5

```

## TABLES Input File for Example 8

```

COMM  TABLES Input File Exam8.TIN
2SWR  1
2SCP  1
ENDF

```

## TABLES Output File for Example 8

MONTHLY SUMMARY TABLE FOR WATER RIGHT WR-1

YEAR	MONIH	AVAILABLE STREAMFLOW (AC-FT)	STIREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	SYSTEM RELEASES (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	SHORTAGE (AC-FT)
1990	1	40000.0	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
1990	2	40000.0	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
1990	3	40000.0	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
1990	4	0.0	0.0	186055.8	3944.2	0.0	10000.0	10000.0	0.0
1990	5	0.0	0.0	172387.7	3668.1	0.0	10000.0	10000.0	0.0
1990	6	0.0	0.0	158990.2	3397.4	0.0	10000.0	10000.0	0.0
1990	7	0.0	0.0	145858.1	3132.1	0.0	10000.0	10000.0	0.0
1990	8	0.0	0.0	132986.0	2872.1	0.0	10000.0	10000.0	0.0
1990	9	0.0	0.0	120368.8	2617.2	0.0	10000.0	10000.0	0.0
1990	10	4000.0	4000.0	111985.5	2383.3	0.0	10000.0	10000.0	0.0
1990	11	4000.0	4000.0	103768.2	2217.3	0.0	10000.0	10000.0	0.0
1990	12	4000.0	4000.0	95713.6	2054.6	0.0	10000.0	10000.0	0.0
1991	1	8000.0	8000.0	88964.4	4749.2	0.0	10000.0	10000.0	0.0
1991	2	8000.0	8000.0	82544.5	4419.9	0.0	10000.0	10000.0	0.0
1991	3	8000.0	8000.0	76437.7	4106.8	0.0	10000.0	10000.0	0.0
1991	4	200000.0	140495.8	200000.0	6933.5	0.0	10000.0	10000.0	0.0
1991	5	200000.0	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
1991	6	200000.0	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
1991	7	0.0	0.0	180198.0	9802.0	0.0	10000.0	10000.0	0.0
1991	8	0.0	0.0	161362.0	8836.0	0.0	10000.0	10000.0	0.0
1991	9	0.0	0.0	143444.8	7917.2	0.0	10000.0	10000.0	0.0
1991	10	4000.0	4000.0	130362.0	7082.8	0.0	10000.0	10000.0	0.0
1991	11	8000.0	8000.0	121877.8	6484.2	0.0	10000.0	10000.0	0.0
1991	12	20000.0	20000.0	125688.6	6189.2	0.0	10000.0	10000.0	0.0
MEAN		32833.3	12104.0	147458.1	5200.3	0.0	10000.0	10000.0	0.0

MONTHLY SUMMARY TABLE FOR WATER RIGHT WR-2

YEAR	MONIH	AVAILABLE STREAMFLOW (AC-FT)	STIREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	SYSTEM RELEASES (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	SHORTAGE (AC-FT)
1990	1	57333.4	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
1990	2	57333.4	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
1990	3	57333.4	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
1990	4	0.0	0.0	186111.3	3888.7	0.0	10000.0	10000.0	0.0
1990	5	0.0	0.0	172497.7	3613.6	0.0	10000.0	10000.0	0.0
1990	6	0.0	0.0	159153.6	3344.1	0.0	10000.0	10000.0	0.0
1990	7	0.0	0.0	146073.8	3079.8	0.0	10000.0	10000.0	0.0
1990	8	0.0	0.0	133253.0	2820.8	0.0	10000.0	10000.0	0.0
1990	9	0.0	0.0	120686.0	2566.9	0.0	10000.0	10000.0	0.0
1990	10	4000.0	4000.0	112336.1	2349.9	0.0	10000.0	10000.0	0.0
1990	11	4000.0	4000.0	104151.6	2184.6	0.0	10000.0	10000.0	0.0
1990	12	4000.0	4000.0	96129.1	2022.5	0.0	10000.0	10000.0	0.0
1991	1	8000.0	8000.0	89446.7	4682.3	0.0	10000.0	10000.0	0.0
1991	2	8000.0	8000.0	83090.4	4356.4	0.0	10000.0	10000.0	0.0
1991	3	8000.0	8000.0	77044.1	4046.3	0.0	10000.0	10000.0	0.0
1991	4	239669.6	139889.4	200000.0	6933.5	0.0	10000.0	10000.0	0.0
1991	5	320000.2	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
1991	6	320000.2	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
1991	7	0.0	0.0	180394.1	9605.9	0.0	10000.0	10000.0	0.0
1991	8	0.0	0.0	161744.5	8649.5	0.0	10000.0	10000.0	0.0
1991	9	0.0	0.0	144004.8	7739.8	0.0	10000.0	10000.0	0.0
1991	10	4000.0	4000.0	131051.5	6953.3	0.0	10000.0	10000.0	0.0
1991	11	8000.0	8000.0	122651.3	6400.2	0.0	10000.0	10000.0	0.0
1991	12	20000.0	20000.0	126424.4	6226.9	0.0	10000.0	10000.0	0.0
MEAN		46652.9	12078.7	147760.2	5144.4	0.0	10000.0	10000.0	0.0

MONTHLY SUMMARY TABLE FOR WATER RIGHT WR-3

YEAR	MONIH	AVAILABLE STREAMFLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	SYSTEM RELEASES (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	SHORTAGE (AC-FT)
1990	1	72000.0	7000.0	100000.0	2000.0	0.0	5000.0	5000.0	0.0
1990	2	72000.0	7000.0	100000.0	2000.0	0.0	5000.0	5000.0	0.0
1990	3	72000.0	7000.0	100000.0	2000.0	0.0	5000.0	5000.0	0.0
1990	4	0.0	0.0	93179.4	1820.6	0.0	5000.0	5000.0	0.0
1990	5	0.0	0.0	86493.9	1685.5	0.0	5000.0	5000.0	0.0
1990	6	0.0	0.0	79940.8	1553.1	0.0	5000.0	5000.0	0.0
1990	7	0.0	0.0	73517.4	1423.4	0.0	5000.0	5000.0	0.0
1990	8	0.0	0.0	67221.3	1296.2	0.0	5000.0	5000.0	0.0
1990	9	0.0	0.0	61049.8	1171.5	0.0	5000.0	5000.0	0.0
1990	10	2000.0	2000.0	56949.2	1100.6	0.0	5000.0	5000.0	0.0
1990	11	2000.0	2000.0	52929.9	1019.3	0.0	5000.0	5000.0	0.0
1990	12	2000.0	2000.0	48990.1	939.8	0.0	5000.0	5000.0	0.0
1991	1	4000.0	4000.0	45795.6	2194.5	0.0	5000.0	5000.0	0.0
1991	2	4000.0	4000.0	42757.0	2038.7	0.0	5000.0	5000.0	0.0
1991	3	4000.0	4000.0	39866.5	1890.4	0.0	5000.0	5000.0	0.0
1991	4	219614.8	68600.2	100000.0	3466.7	0.0	5000.0	5000.0	0.0
1991	5	460000.0	10000.0	100000.0	5000.0	0.0	5000.0	5000.0	0.0
1991	6	460000.0	10000.0	100000.0	5000.0	0.0	5000.0	5000.0	0.0
1991	7	0.0	0.0	90627.4	4372.6	0.0	5000.0	5000.0	0.0
1991	8	0.0	0.0	81712.0	3915.4	0.0	5000.0	5000.0	0.0
1991	9	0.0	0.0	73231.5	3480.5	0.0	5000.0	5000.0	0.0
1991	10	2000.0	2000.0	67039.2	3192.3	0.0	5000.0	5000.0	0.0
1991	11	4000.0	4000.0	63023.5	3015.7	0.0	5000.0	5000.0	0.0
1991	12	10000.0	10000.0	64827.2	3196.3	0.0	5000.0	5000.0	0.0
MEAN		57900.6	5983.3	74548.0	2448.9	0.0	5000.0	5000.0	0.0

MONTHLY SUMMARY TABLE FOR CONTROL POINT CP1

YEAR	MONIH	NATURALIZED STREAMFLOW (AC-FT)	REGULATED STREAMFLOW (AC-FT)	UNAPPROPRIATED STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	EOP STORAGE (AC-FT)	NET EVAPORATION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1990	1	100000.0	65000.0	65000.0	0.0	35000.0	500000.0	10000.0	25000.0	0.0
1990	2	100000.0	65000.0	65000.0	0.0	35000.0	500000.0	10000.0	25000.0	0.0
1990	3	100000.0	65000.0	65000.0	0.0	35000.0	500000.0	10000.0	25000.0	0.0
1990	4	0.0	0.0	0.0	0.0	0.0	465346.6	9653.5	25000.0	0.0
1990	5	0.0	0.0	0.0	0.0	0.0	431379.2	8967.3	25000.0	0.0
1990	6	0.0	0.0	0.0	0.0	0.0	398084.6	8294.6	25000.0	0.0
1990	7	0.0	0.0	0.0	0.0	0.0	365449.3	7635.3	25000.0	0.0
1990	8	0.0	0.0	0.0	0.0	0.0	333460.2	6989.1	25000.0	0.0
1990	9	0.0	0.0	0.0	0.0	0.0	302104.6	6355.6	25000.0	0.0
1990	10	10000.0	0.0	0.0	0.0	10000.0	281270.8	5833.8	25000.0	0.0
1990	11	10000.0	0.0	0.0	0.0	10000.0	260849.6	5421.2	25000.0	0.0
1990	12	10000.0	0.0	0.0	0.0	10000.0	240832.8	5016.8	25000.0	0.0
1991	1	20000.0	0.0	0.0	0.0	20000.0	224206.8	11626.0	25000.0	0.0
1991	2	20000.0	0.0	0.0	0.0	20000.0	208391.8	10815.0	25000.0	0.0
1991	3	20000.0	0.0	0.0	0.0	20000.0	193348.3	10043.5	25000.0	0.0
1991	4	500000.0	151014.6	151014.6	0.0	348985.4	500000.0	17333.7	25000.0	0.0
1991	5	500000.0	450000.0	450000.0	0.0	50000.0	500000.0	25000.0	25000.0	0.0
1991	6	500000.0	450000.0	450000.0	0.0	50000.0	500000.0	25000.0	25000.0	0.0
1991	7	0.0	0.0	0.0	0.0	0.0	451219.5	23780.5	25000.0	0.0
1991	8	0.0	0.0	0.0	0.0	0.0	404818.6	21400.9	25000.0	0.0
1991	9	0.0	0.0	0.0	0.0	0.0	360681.1	19137.5	25000.0	0.0
1991	10	10000.0	0.0	0.0	0.0	10000.0	328452.7	17228.3	25000.0	0.0
1991	11	20000.0	0.0	0.0	0.0	20000.0	307552.6	15900.1	25000.0	0.0
1991	12	50000.0	0.0	0.0	0.0	50000.0	316940.3	15612.3	25000.0	0.0
MEAN		82083.3	51917.3	51917.3	0.0	30166.1	369766.2	12793.5	25000.0	0.0

### Example 9 Featuring Flow Switch FS Record Target Setting Capabilities

The purpose of Example 9 is to illustrate the use of the flow switch *FS* record. The very simple system consists of two control points and one diversion. The diversion at control point CP-1 is a function of the cumulative total regulated flow during the current month and preceding 11 months at CP-2. The monthly diversion target is 333.33 acre-feet/month if the 12-month cumulative regulated flow volume at CP-2 falls within the following range:

$$3,000 \text{ acre-feet} \leq \text{Regulated Flow} \leq 9,000 \text{ acre-feet}$$

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

Regulated flow is selected as the flow switch variable *FSV* entered in *FS* record field 2. The blank *FS* record field 11 activates the default *FSI(FS,4)* option 1 in which the current month is included along with the 11 preceding months (*FS* record field 8) in totaling cumulative flow volume. Using regulated flow as the flow switch variable for setting the diversion target is complicated by the fact that the regulated flow in the current month is dependent upon the diversion target. The cumulative regulated flow consists of the summation of actual regulated flow volumes in the 11 preceding months plus, for the current month, the latest regulated flow in the water right priority sequence computations prior to this right. With no other senior rights, the naturalized flow is used for the regulated flow in the current month. If *FS(FS,4)* in field 11 is changed to option 3, the current month is not included in the flow summation, only the field 8 *FS(FS,1)* preceding months.

### WRAP-SIM Input DAT File for Example 9

```

T1 WRAP-SIM Input File Exam9.DAT
T2 Example 9 from Appendix B of Reference Manual
T3 Illustrating Flow Switch FS Record
**
**      1      2      3      4      5      6      7      8
**34567890123456789012345678901234567890123456789012345678901234567890
**      !      !      !      !      !      !      !      !
JD      4      2001      1      -1      -1
JO      3
**
CP CP-1      CP-2
CP CP-2      OUT
**
WR CP-1      12000
FS      1      CP-2      3000.      9000.      0.33333      1.0      11
ED
**      !      !      !      !      !      !      !      !
**      1      2      3      4      5      6      7      8
**34567890123456789012345678901234567890123456789012345678901234567890
**
IN CP-1      2001      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.
IN CP-2      2001      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.
IN CP-1      2002      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN CP-2      2002      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN CP-1      2003      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.      1000.
IN CP-2      2003      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.      2000.
IN CP-1      2004      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN CP-2      2004      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.

```

### TABLES Input TIN File for Example 9

```

COMM TABLES Input File Exam9.TIN
COMM Example 9 from Reference Manual
****      1      2      3
****56789012345678901234567890123456
****      !      !      !      !      !      !      !
2TAR      1      0      0      1      1
IDEN      Flow Switch
2DIV      1      0      0      1     -1
2REG      1      0      0      0      1
IDEN      CP-2
2REG      1      0      0      0     -1          2     12
ENDF

```

### TABLES Output TOU File for Example 9

#### DIVERSION TARGETS (AC-FT) FOR WATER RIGHT Flow Switch

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	1000.00	333.33	333.33	333.33	333.33	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	9333.32
2002	1000.00	1000.00	1000.00	333.33	333.33	333.33	333.33	333.33	333.33	1000.00	1000.00	1000.00	7999.98
2003	1000.00	333.33	333.33	333.33	333.33	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	9333.32
2004	1000.00	1000.00	1000.00	333.33	333.33	333.33	333.33	333.33	333.33	1000.00	1000.00	1000.00	7999.98
MEAN	1000.00	666.66	666.66	333.33	333.33	666.67	666.67	666.67	666.67	1000.00	1000.00	1000.00	8666.65

#### DIVERSIONS (AC-FT) FOR WATER RIGHT Flow Switch

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	1000.00	333.33	333.33	333.33	333.33	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	9333.32
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	1000.00	333.33	333.33	333.33	333.33	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	9333.32
2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEAN	500.00	166.66	166.66	166.66	166.66	500.00	500.00	500.00	500.00	500.00	500.00	500.00	4666.66

#### REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP-2

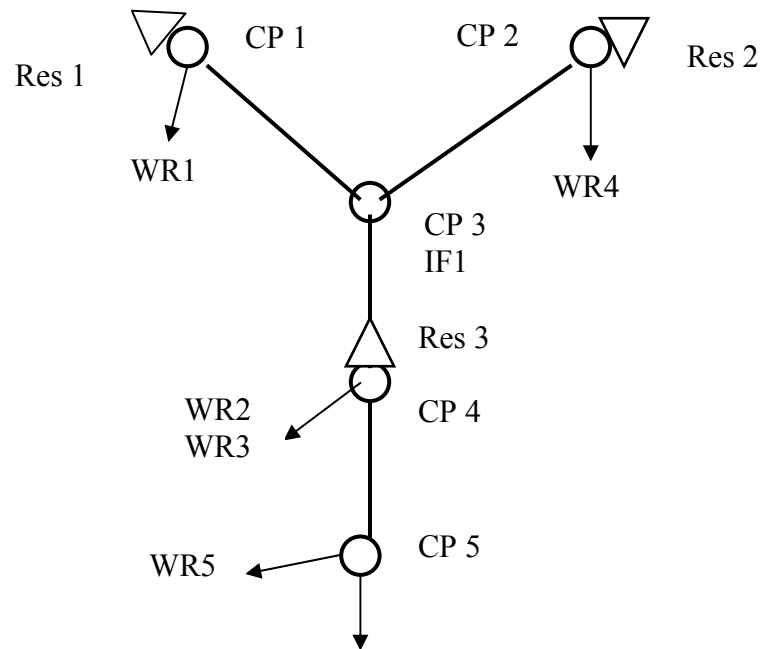
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	1000.	1667.	1667.	1667.	1667.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	14667.
2002	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2003	1000.	1667.	1667.	1667.	1667.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	14667.
2004	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	500.	833.	833.	833.	833.	500.	500.	500.	500.	500.	500.	500.	7333.

#### REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP-2 MOVING TOTAL FOR 12 MONTHS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	1000.	2667.	4333.	6000.	7667.	8667.	9667.	10667.	11667.	12667.	13667.	14667.	103333.
2002	13667.	12000.	10333.	8667.	7000.	6000.	5000.	4000.	3000.	2000.	1000.	0.	72667.
2003	1000.	2667.	4333.	6000.	7667.	8667.	9667.	10667.	11667.	12667.	13667.	14667.	103333.
2004	13667.	12000.	10333.	8667.	7000.	6000.	5000.	4000.	3000.	2000.	1000.	0.	72667.
MEAN	7333.	7333.	7333.	7333.	7333.	7333.	7333.	7333.	7333.	7333.	7333.	7333.	88000.

### Example 10 with Subordination Agreement

Example 10 illustrates the strategy outlined in the last section of Chapter 4 for combining *PX* and *BU* record features to model a subordination agreement. Water rights WR1 and WR2 in Example 10 are equivalent to water rights JJJ and SSS in Figure 4.4. Water right WR1 is junior to water right WR2 located downstream. However, according to the subordination agreement, the junior WR1 is not required to pass inflows through control point CP1 to maintain flows to meet requirements of WR2. WR3 is a backup right that serves the sole purpose of modeling the increases in stream flow depletions incurred by WR1 that must be mitigated by the subordinated senior right WR2. WR4, WR5, and IF1 are third-party rights that are not associated with the subordination agreement.



**System Schematic for Example 10**

## WRAP-SIM Input DAT File for Example 10

```

T1 WRAP-SIM Input File Exam10.DAT
T2 Example 10 from Appendix B of Reference Manual
** Simulation of a Subordination Agreement by Combining
** PX Record XCP and Dual Options and BU Record
**
**      1      2      3      4      5      6      7
**3456789012345678901234567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !
JD      2      2001      8      -1      -1      4
JO      -1
RO      2      Res 1      Res 3
**
CP      CP1      CP3      NONE
CP      CP2      CP3      NONE
CP      CP3      CP4      NONE
CP      CP4      CP5      NONE
CP      CP5      OUT      NONE
** -----
** Water rights WR1, WR2, and WR3 with PX records are associated
** with the subordination agreement.
**
** WR1 does not pass inflows for senior WR2 located downstream.
** Control point availability limit option is activated.
WR      CP1      7200.      1985      WR1
WS Res 1      5000.      .1      1.
PX      2      2      CP4
** -----
** WR2 is subordinated to the junior WR1.
** Dual pass option is activated to constrain flow depletions.
WR      CP4      6000.      1950      WR2
WS Res 3      8000.      .1      1.
PX      3
** -----
** WR3 is a backup right backing up WR1 from WR2 reservoir storage.
WR      CP4      2001      WR3
WS Res 3      8000.
BU      0      0      WR1
PX      2
** -----
** Water rights WR4, WR5, and IF1 are not associated
** with the subordination agreement.
**
WR      CP2      3600.      1978      WR4
WS Res 2      5000.      .1      1.
** -----
WR      CP5      4800.      1927      WR5
** -----
IF      CP3      1200.      1920      IF1
**      !      !      !      !      !      !      !      !
**      1      2      3      4      5      6      7
**3456789012345678901234567890123456789012345678901234567890123456789012
ED

```



## WRAP-SIM Naturalized Flow Input FLO File for Example 10

```

** WRAP-SIM Input File Exam10.FLO
** Example 10 from Appendix B of Reference Manual
**
** Naturalized Streamflow
**
IN  CP1  2001  600  600  600  600  600  600  600  600  600  600  600  600  600
IN  CP2  2001  300  300  300  300  300  300  300  300  300  300  300  300  300
IN  CP3  2001  900  900  900  900  900  900  1200 1200 1200 1200 1200 1200
IN  CP4  2001 1000 1000 1000  900  900  900  1200 1200 1200 1200 1200 1200
IN  CP5  2001 1400 1400 1400 1400 1400  900 1600 1600 1600 2000 2000 2000
IN  CP1  2002 4000 4000 4000  0  0  0  200 200 200 4000 4000 4000
IN  CP2  2002 4000 4000 4000  300 300 300 300 300 300 300 300 300
IN  CP3  2002 4000 8000 8000  500 500 500 500 500 500 4300 4400 5000
IN  CP4  2002 4000 8000 8000  500 500 500 500 500 500 500 500 500
IN  CP5  2002 5000 9000 8000  900 900 900 900 500 500 1000 3000 5000

```

## WRAP-SIM Message MSS File for Example 10

```

WRAP-SIM MESSAGE FILE

*** Starting to read file Exam10.DAT
*** JD record was read.
*** JO record was read.
*** Reading RO record.
*** Starting to read UC records.
*** Finished reading UC records.
*** Starting to read CP records.
*** Finished reading CP records.
*** Starting to read IF/WR records.
*** Finished reading IF/WR records.
*** Finished reading file Exam10.DAT
*** Starting to open remaining files.
*** Opened file Exam10.FLO
*** Opened file Exam10.OUT
*** Finished opening files.
*** Finished ranking water rights in priority order.

*****
System components counted from input file:
    5 control points (CP records)
    3 reservoirs
    1 instream flow rights (IF records)
    5 all water rights except IF rights (WR records)
    3 dual simulation rights
*****

*** Beginning annual loop.
*** 5 IN and 0 EV records were read for the first year (2001).
*** Negative incremental flow adjustments were performed for the first year.
*** End of input data trace.
*** Rights with DUAL greater than zero are listed as follows:
      WR2          DUAL(wr)= 3   CP4          Res 3
      WR1          DUAL(wr)= 2   CP1          Res 1
      WR3          DUAL(wr)= 2   CP4          Res 3
*** Streamflow depletions from the initial simulation for DUAL of 3 or 4 are as follows.
Water Right: WR2
2001  500.0  500.0  500.0  500.0  500.0  500.0  500.0  500.0  500.0  500.0  500.0  500.0
2002  500.0  500.0  500.0  500.0  500.0  500.0  500.0  100.0 100.0  500.0  500.0  500.0
*** Initial simulation was completed.
*** The dual simulation option is activated by DUAL of 3 or 5
    on the PX or SO record of one or more rights.
*** Beginning annual loop.
*** 5 IN and 0 EV records were read for the first year (2001).
*** Negative incremental flow adjustments were performed for the first year.
*** End of input data trace.

***** Normal Completion of Program WRAP-SIM *****

```

### TABLES Input TIN File for Example 10

```

COMM TABLES Input File Exam10.TIN
COMM Example 10 from Appendix B of Reference Manual
**      1      2      3      4      5
** 567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !      !      !      !
2TAR  1      0      0      1      3
IDEN  WR1                    WR2                    WR3
2SHT  1      0      0      1     -3
2DIV  1      0      0      1     -3
2XAV  1      0      0      1      1
IDEN  WR1
2STO  1      0      0      2      0
ENDF
    
```

### TABLES Output File for Example 10

#### DIVERSION TARGETS (AC-FT) FOR WATER RIGHT WR1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00
2002	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00
MEAN	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00

#### DIVERSION TARGETS (AC-FT) FOR WATER RIGHT WR2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00
2002	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00
MEAN	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00

#### DIVERSION TARGETS (AC-FT) FOR WATER RIGHT WR3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	300.00	300.00	300.00	400.00	400.00	500.00	200.00	200.00	200.00	200.00	200.00	200.00	3400.00
2002	0.00	0.00	0.00	0.00	0.00	0.00	200.00	100.00	100.00	500.00	0.00	0.00	900.00
MEAN	150.00	150.00	150.00	200.00	200.00	250.00	200.00	150.00	150.00	350.00	100.00	100.00	2150.00

#### DIVERSION SHORTAGES (AC-FT) FOR WATER RIGHT WR1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

#### DIVERSION SHORTAGES (AC-FT) FOR WATER RIGHT WR2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DIVERSION SHORTAGES (AC-FT) FOR WATER RIGHT WR3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DIVERSIONS (AC-FT) FOR WATER RIGHT WR1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00
2002	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00
MEAN	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	600.00	7200.00

DIVERSIONS (AC-FT) FOR WATER RIGHT WR2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00
2002	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00
MEAN	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	6000.00

DIVERSIONS (AC-FT) FOR WATER RIGHT WR3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	300.00	300.00	300.00	400.00	400.00	500.00	200.00	200.00	200.00	200.00	200.00	200.00	3400.00
2002	0.00	0.00	0.00	0.00	0.00	0.00	200.00	100.00	100.00	500.00	0.00	0.00	900.00
MEAN	150.00	150.00	150.00	200.00	200.00	250.00	200.00	150.00	150.00	350.00	100.00	100.00	2150.00

INCREASE IN AVAILABLE STREAMFLOW RESULTING FROM  
PX RECORD CP LIMIT OPTION FOR WATER RIGHT WR1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2001	300.0	300.0	300.0	400.0	400.0	500.0	200.0	200.0	200.0	200.0	200.0	200.0	3400.0
2002	0.0	0.0	0.0	0.0	0.0	0.0	200.0	100.0	100.0	500.0	500.0	200.0	1600.0
MEAN	150.0	150.0	150.0	200.0	200.0	250.0	200.0	150.0	150.0	350.0	350.0	200.0	2500.0

END-OF-PERIOD STORAGE (AC-FT) FOR RESERVOIR Res 1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2001	4900.0	4800.0	4700.0	4600.0	4500.0	4400.0	4400.0	4400.0	4400.0	4400.0	4400.0	4400.0	4525.0
2002	5000.0	5000.0	5000.0	4400.0	3800.0	3200.0	2800.0	2300.0	1800.0	4800.0	5000.0	5000.0	4008.3
MEAN	4950.0	4900.0	4850.0	4500.0	4150.0	3800.0	3600.0	3350.0	3100.0	4600.0	4700.0	4700.0	4266.7

END-OF-PERIOD STORAGE (AC-FT) FOR RESERVOIR Res 3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2001	7700.0	7400.0	7100.0	6700.0	6300.0	5800.0	5600.0	5400.0	5200.0	5000.0	4800.0	4600.0	5966.7
2002	7100.0	8000.0	8000.0	8000.0	8000.0	8000.0	7800.0	7300.0	6800.0	6300.0	6300.0	6300.0	7325.0
MEAN	7400.0	7700.0	7550.0	7350.0	7150.0	6900.0	6700.0	6350.0	6000.0	5650.0	5550.0	5450.0	6645.8

## APPENDIX C WRAP-HYD EXAMPLES

An "Introduction to Appendices B and C" is presented at the beginning of Appendix B. The examples illustrate the content and format of the input and output. They also provide a starting point for creating other datasets containing other features of interest to model users. Model users should experiment with simple datasets to become proficient with various modeling features prior to application to complex real world river basins. Model results with simplified data are easily trackable. Users can compare computer results with manual computational checks to confirm that the programs work as expected.

Five simple examples are provided to illustrate *WRAP-HYD* input and output datasets. Examples 11, 12, and 13 demonstrate basic *AS*, *FA*, *RS*, *SC*, *CI* record stream flow adjustment features and also include *EP* record evaporation-precipitation manipulations. Examples 11 and 12 are identical except for the format of the input and output. Example 12 is included to further illustrate input/output format options. *IN* and *EV* records in Examples 11 and 13 are input in the optional control point grouping format and output in standard format. Example 12 uses the columnar table format for the stream flow input file rather than *IN* records. Example 14 focuses on distribution of stream flows from gaged to ungaged control points. *IN* records for Example 14 are provided alternatively as a standard-format FLO file and an old-format root1.HYD file. Example 15 employs the *OI* record to convert *WRAP-SIM* simulation results from an OUT file to *SIM* or *HYD* input records written to a *HYD* output HOT file.

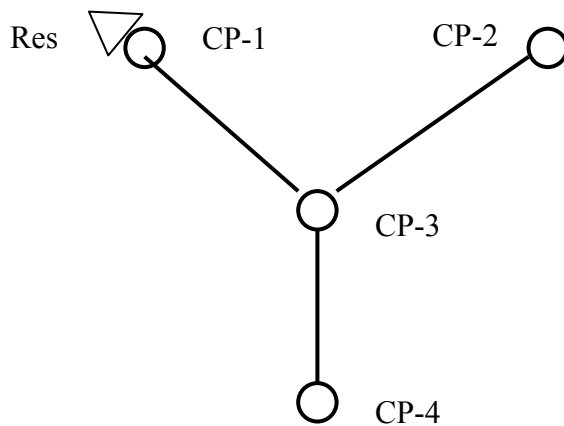
### Example 11

The Example 11 river basin configuration is represented by four control points (labeled CP-1, CP-2, CP-3, CP-4) representing actual locations in the river system. Two other control points (CP1E and CP2P) serve as identifiers for evaporation (CP1E) and precipitation (CP1P) datasets for reservoir Res located at CP-1. An input file with filename Exam11.DAT contains:

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

Evaporation and precipitation depths (*EV* records) are provided in file Exam11.EVA with the control point identifiers CP1E and CP1P. The same sets of 12 monthly evaporation and precipitation depths are repeated for each of the three years of the period-of-analysis. An *EP* record in the DAT file specifies that the precipitation be subtracted from the evaporation, and that the resulting net evaporation-precipitation depths be assigned to control point CP-1. The output file Exam11OUT.EVA contains only the computed *EV* records for CP-1. *EV* records for all other control points are omitted from the output file as specified by parameter INEV on the *CP* records. The net evaporation-precipitation depths are also used in the reservoir evaporation-precipitation computations performed in adjusting stream flows as instructed by the *RS* record.

Observed stream flows (*IN* records) are provided as an inflow file with the filename Exam11.FLO. The stream flows are adjusted as specified by *AS* records using data from *FA* and *RS/SC* records. Each adjustment occurs at a specified control point and all downstream locations. Channel losses are considered in cascading the adjustments through the reach below CP-3. Stream flows at CP-2 and downstream control points CP-3 and CP-4 are adjusted based on inflows/outflows provided on *FA* records for all three years of the period-of-analysis. Stream flows at CP-1 and downstream control points CP-3 and CP-4 are adjusted for the effects of the reservoir at CP-1 following the specifications from the *RS* record. The default selection of components to include in the reservoir adjustments is adopted. The stream flow adjustments for the effects of the reservoir cover the last two years of the three-year hydrologic period-of-analysis.



**Control Point System Schematic for Example 11**

The configuration of the river basin system is shown in the above schematic. The three input files and four output files are presented on the following pages. The filenames (root.extension) of the input files have a root1 of *Exam11* and extensions *DAT*, *FLO*, and *EVA*. The output filenames have a root2 of *Exam11OUT* and extensions *HMS*, *HOT*, *FLO* and *EVA*. The automatic *WRAP-HYD* default convention was adopted in which program *HYD* internally creates root2 by adding *OUT* to root1.

The message file Exam11OUT.HMS tracks program progress in reading the input files, performing computations, and developing output files. The *WRAP-HYD* output files Exam11OUT.FLO and Exam11OUT.EVA contain the final adjusted flows and evaporation-precipitation depths in formats specified by *JC* records fields 12 and 13 that illustrating two different alternative format options. The EVA output file is in standard *EV* record format designed to serve as an input file for *WRAP-SIM*. The table in the FLO output file is a tabulation of the final adjusted stream flows as specified by *JC* record field 12 in a column format that facilitates transporting the data to a spreadsheet program such as *Microsoft Excel* for plotting or various computational manipulations. The *HYD* output HOT file contains a table, which is activated by an entry in *RS* record field 8 that shows the intermediate results of determining stream flow adjustments for the effects of the reservoir.

## WRAP-HYD Input HIN File for Example 11

```

** WRAP-HYD Input File Exam11.HIN
** Example 11 from Appendix C of Reference Manual
**
**      1      2      3      4      5      6      7      8      9
**3456789012345678901234567890123456789012345678901234567890123456
**      !      !      !      !      !      !      !      !      !      !      !      !      !      !      !      !      !      !
**
JC 2005  3  1  2  2  1  0  0  0  0  5  1  0  1
**
** CP records for four actual control points (CP-1, CP-2, CP-3, and CP-4) and
** evaporation (CP1E) and precipitation (CP1P) data set identifiers for CP-1.
**
CP CP1E          2  none
CP CP1P          4  2  none
CP CP-1  CP-3          none 10000.
CP CP-2  CP-3          2  none
CP CP-3  CP-4          2  none          0.3
CP CP-4  OUT          2  2  CP-3  none
**
** The net evaporation-precipitation for CP-1 is computed by subtracting the
** precipitation assigned to CP1P from the evaporation entered with CP1E.
**
EP CP-1  CP1E      1.0  CP1P      -1.0
**
** FA record adjustments at CP-2 and downstream control points for three years.
**
AS CP-2          3
FA 100      100      100      100      100      100      -100      -100      -100      0      0      0
FA 100      100      100      100      100      100      -100      -100      -100      0      0      0
FA 100      100      100      100      100      100      -100      -100      -100      0      0      0
**
** Reservoir Res-A adjustments at CP-1 and downstream control points for two years.
**
AS CP-1  2006  2007  2          3
RS Res          1  2000  0.1  1.0          2000
SC 2000  2000  1500  1000  500  0  1000  2000  3000  2500  2000  1500
SC 2000  2000  1500  1000  500  0  1000  2000  3000  2500  2000  1500
**
ED

```

## WRAP-HYD FLO Input File for Example 11

```

** WRAP-HYD Input File Exam11.FLO
** Example 11 from Appendix C of Reference Manual
** Gaged Streamflows in acre-feet
**
IN CP-1  2005  1000  1000  1000  1000  1000  1000  1000  1000  1000  1000  1000  1000
IN CP-1  2006  500  500  500  500  500  500  500  500  500  500  500  500
IN CP-1  2007  0  0  0  0  0  0  0  0  0  0  0  0
IN CP-2  2005  1000  1000  1000  1000  1000  1000  1000  1000  1000  1000  1000  1000
IN CP-2  2006  500  500  500  500  500  500  500  500  500  500  500  500
IN CP-2  2007  0  0  0  0  0  0  0  0  0  0  0  0
IN CP-3  2005  3000  3000  3000  3000  3000  3000  3000  3000  3000  3000  3000  3000
IN CP-3  2006  2000  2000  2000  2000  2000  2000  2000  2000  2000  2000  2000  2000
IN CP-3  2007  0  0  0  0  0  0  0  0  0  0  0  0

```

## WRAP-HYD EVA Input File for Example 11

```

** WRAP-HYD Input File Exam11.EVA
** Example 11 from Appendix C of Reference Manual
** Evaporation (CP1E) and Precipitation (CP1P) for Control Point CP-1 in feet
**
EV CP1E20052007  1.5  1.5  1.5  0.3  0.3  0.3  0.2  0.2  0.2  1.4  1.4  1.4
EV CP1P20052007  0.5  0.5  0.5  0.8  0.8  0.8  0.1  0.1  0.1  1.4  1.4  1.4

```

## WRAP-HYD Message HMS File for Example 11

WRAP-HYD MESSAGE FILE

```
*** Starting to read file exam11.HIN
*** JC record was read.
*** Starting to read CP records.
*** Finished reading CP records.
*** Reading EP records.
*** Read one EP record.
*** Finished reading file exam11.HIN
*****
Number of CP, SV/SA, OI, EP, AN, AS, EQ records read from HIN file.
    6 control point CP records
    3 control points with streamflows read as input
    2 control points with evap-precip read as input
    1 evaporation-precipitation combining EP records
    2 streamflow adjustment AS records
*****
*** Starting to read IN and/or EV records in JC(1),JC(2)=2 format.
*** Reordering IN records and multiplying by factors on CP records.
*** Finished reading IN records from FLO file in JC(1)=2 format.
*** Starting to read EV records from EVA file in JC(2)=2 format.
*** Reordering EV records and multiplying by factors on CP records.
*** Finished reading IN and/or EV records.
*** Starting EP record operations.
*** Finished EP record operations.
*** Starting to adjust flows as specified by AS and/or EQ records.
*** Finished AS and/or EQ record operations
*** Starting to write IN and/or EV records.
*** Finished writing IN and/or EV records.
*** Starting to write streamflows to FLO file in columnar format.
*** Finished writing flows in columnar format.

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

## WRAP-HYD FLO Output File for Example 11

WRAP-HYD Output File exam11OUT.FLO

Year	Mon	CP1E	CP1P	CP-1	CP-2	CP-3	CP-4
2005	1	0.0	0.0	1000.0	1100.0	3100.0	3070.0
2005	2	0.0	0.0	1000.0	1100.0	3100.0	3070.0
2005	3	0.0	0.0	1000.0	1100.0	3100.0	3070.0
2005	4	0.0	0.0	1000.0	1100.0	3100.0	3070.0
2005	5	0.0	0.0	1000.0	1100.0	3100.0	3070.0
2005	6	0.0	0.0	1000.0	1100.0	3100.0	3070.0
2005	7	0.0	0.0	1000.0	900.0	2900.0	2930.0
2005	8	0.0	0.0	1000.0	900.0	2900.0	2930.0
2005	9	0.0	0.0	1000.0	900.0	2900.0	2930.0
2005	10	0.0	0.0	1000.0	1000.0	3000.0	3000.0
2005	11	0.0	0.0	1000.0	1000.0	3000.0	3000.0
2005	12	0.0	0.0	1000.0	1000.0	3000.0	3000.0
2006	1	0.0	0.0	710.0	600.0	2310.0	2217.0
2006	2	0.0	0.0	710.0	600.0	2310.0	2217.0
2006	3	0.0	0.0	183.8	600.0	1783.8	1848.6
2006	4	0.0	0.0	0.0	600.0	1600.0	1720.0
2006	5	0.0	0.0	0.0	600.0	1600.0	1720.0
2006	6	0.0	0.0	0.0	600.0	1600.0	1720.0
2006	7	0.0	0.0	1507.5	400.0	2907.5	2635.2
2006	8	0.0	0.0	1522.5	400.0	2922.5	2645.8
2006	9	0.0	0.0	1537.5	400.0	2937.5	2656.2
2006	10	0.0	0.0	13.8	500.0	1513.8	1659.6
2006	11	0.0	0.0	11.2	500.0	1511.2	1657.9
2006	12	0.0	0.0	8.8	500.0	1508.8	1656.1
2007	1	0.0	0.0	675.0	100.0	775.0	542.5
2007	2	0.0	0.0	200.0	100.0	300.0	210.0
2007	3	0.0	0.0	0.0	100.0	100.0	70.0
2007	4	0.0	0.0	0.0	100.0	100.0	70.0
2007	5	0.0	0.0	0.0	100.0	100.0	70.0
2007	6	0.0	0.0	0.0	100.0	100.0	70.0
2007	7	0.0	0.0	1005.0	0.0	1005.0	703.5
2007	8	0.0	0.0	1015.0	0.0	1015.0	710.5
2007	9	0.0	0.0	1025.0	0.0	1025.0	717.5
2007	10	0.0	0.0	0.0	0.0	0.0	0.0
2007	11	0.0	0.0	0.0	0.0	0.0	0.0
2007	12	0.0	0.0	0.0	0.0	0.0	0.0

## WRAP-HYD EVA Output File for Example 11

WRAP-HYD Output File Exam11OUT.EVA

EV	CP-1	2005	1.00	1.00	1.00	-0.50	-0.50	-0.50	0.10	0.10	0.10	0.00	0.00	0.00
EV	CP-1	2006	1.00	1.00	1.00	-0.50	-0.50	-0.50	0.10	0.10	0.10	0.00	0.00	0.00
EV	CP-1	2007	1.00	1.00	1.00	-0.50	-0.50	-0.50	0.10	0.10	0.10	0.00	0.00	0.00



## WRAP-HYD Output HOT File for Example 11

WRAP-HYD Output File Exam11OUT.HOT

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

Year Month Adjustment		Ending Storage (ac-ft)	Mean Area (acres)	Runoff Depth (feet)	RS(1)&RS(2) Storage Change (ac-ft)	RS(3) Spill (ac-ft)	RS(4) Precip -Evap (ac-ft)	RS(5) Site Runoff (ac-ft)	Total (ac-ft)
2006	1	2000.0	200.0	0.050	0.0	0.0	200.0	10.0	210.0
2006	2	2000.0	200.0	0.050	0.0	0.0	200.0	10.0	210.0
2006	3	1500.0	175.0	0.050	-500.0	0.0	175.0	8.8	-316.3
2006	4	1000.0	125.0	0.050	-500.0	0.0	-62.5	6.3	-556.3
2006	5	500.0	75.0	0.050	-500.0	0.0	-37.5	3.8	-533.8
2006	6	0.0	25.0	0.050	-500.0	0.0	-12.5	1.3	-511.3
2006	7	1000.0	50.0	0.050	1000.0	0.0	5.0	2.5	1007.5
2006	8	2000.0	150.0	0.050	1000.0	0.0	15.0	7.5	1022.5
2006	9	3000.0	250.0	0.050	1000.0	0.0	25.0	12.5	1037.5
2006	10	2500.0	275.0	0.050	0.0	500.0	0.0	13.8	-486.3
2006	11	2000.0	225.0	0.050	0.0	500.0	0.0	11.3	-488.8
2006	12	1500.0	175.0	0.050	-500.0	0.0	0.0	8.8	-491.3
2007	1	2000.0	175.0	0.000	500.0	0.0	175.0	0.0	675.0
2007	2	2000.0	200.0	0.000	0.0	0.0	200.0	0.0	200.0
2007	3	1500.0	175.0	0.000	-500.0	0.0	175.0	0.0	-325.0
2007	4	1000.0	125.0	0.000	-500.0	0.0	-62.5	0.0	-562.5
2007	5	500.0	75.0	0.000	-500.0	0.0	-37.5	0.0	-537.5
2007	6	0.0	25.0	0.000	-500.0	0.0	-12.5	0.0	-512.5
2007	7	1000.0	50.0	0.000	1000.0	0.0	5.0	0.0	1005.0
2007	8	2000.0	150.0	0.000	1000.0	0.0	15.0	0.0	1015.0
2007	9	3000.0	250.0	0.000	1000.0	0.0	25.0	0.0	1025.0
2007	10	2500.0	275.0	0.000	0.0	500.0	0.0	0.0	-500.0
2007	11	2000.0	225.0	0.000	0.0	500.0	0.0	0.0	-500.0
2007	12	1500.0	175.0	0.000	-500.0	0.0	0.0	0.0	-500.0
Adjustment Means					62.5	83.3	41.2	4.0	24.4

## Example 12

Example 12 consists of repeating Example 11 using different input data options. The sole purpose of Example 12 is to further illustrate variations in input options. Numeric data for the majority of the input records in the files Exam12.HIN and Exam12.EVA are entered in comma-delimited format rather than the standard fixed-width-field format adopted in Example 11. Fixed-width format is recommended since it is easier for people to read, but the comma-delimited format is also an option. The stream flows are entered in file Exam12.FLO as columns of a table rather than as *IN* records. The output files Exam12OUT.FLO and Exam12OUT.EVA are in standard *IN* and *EV* record format.

### **WRAP-HYD Input HIN File for Example 12**

```
** WRAP-HYD Input File Exam12.HIN
** Example 12 from Appendix C of Reference Manual
** Examples 11 and 12 are identical except for format options.
**
JC 2005,3,1,5,2,1,0,0,0,0,1,1,
**
** CP records for four actual control points (CP-1, CP-2, CP-3, and CP-4) and
** evaporation (CP1E) and precipitation (CP1P) data set identifiers for CP-1.
**
CP CP1E                2    none
CP CP1P                4    2    none
CP CP-1    CP-3                none 10000.
CP CP-2    CP-3                2    none
CP CP-3    CP-4                2    none                0.3
CP CP-4    OUT                2    2    CP-3    none
**
** The net evaporation-precipitation for CP-1 is computed by subtracting the
** precipitation assigned to CP1P from the evaporation entered with CP1E.
**
EP CP-1    CP1E    1.0    CP1P    -1.0
**
** FA record adjustments at CP-2 and downstream control points for three years.
**
AS CP-2,,,,,,3
FA 100,100,100,100,100,100,-100,-100,-100,,,,
FA 100,100,100,100,100,100,-100,-100,-100,,,,
FA 100,100,100,100,100,100,-100,-100,-100,,,,
**
** Reservoir Res-A adjustments at CP-1 and downstream control points for two years.
**
AS CP-1 2006,2007,-2,,,,3,
RS Res ,,,,,,2000,0.1,1.0,0.0,2000,
SC CP-1 2006,2000,2000,1500,1000,500,0,1000,2000,3000,2500,2000,1500,
SC CP-1 2007,2000,2000,1500,1000,500,0,1000,2000,3000,2500,2000,1500,
**
ED
```

### **WRAP-HYD EVA Input File for Example 12**

```
** WRAP-HYD Input File Exam12.EVA
** Example 12 from Appendix C of WRAP Reference/Users Manual
** Evaporation (CP1E) and Precipitation (CP1P) for Control Point CP-1 in feet
**
EV CP1E20052007 1.5,1.5,1.5,0.3,0.3,0.3,0.2,0.2,0.2,1.4,1.4,1.4,
EV CP1P20052007 0.5,0.5,0.5,0.8,0.8,0.8,0.1,0.1,0.1,1.4,1.4,1.4,
```

## WRAP-HYD FLO Input File for Example 12

```

** WRAP-HYD Input File Exam12.FLO
** Example 12 from Appendix C of Reference Manual
** Streamflows in Columnar Format
**

```

Year	Mon	CP-1	CP-2	CP-3
2005	1	1000.0	1000.0	3000.0
2005	2	1000.0	1000.0	3000.0
2005	3	1000.0	1000.0	3000.0
2005	4	1000.0	1000.0	3000.0
2005	5	1000.0	1000.0	3000.0
2005	6	1000.0	1000.0	3000.0
2005	7	1000.0	1000.0	3000.0
2005	8	1000.0	1000.0	3000.0
2005	9	1000.0	1000.0	3000.0
2005	10	1000.0	1000.0	3000.0
2005	11	1000.0	1000.0	3000.0
2005	12	1000.0	1000.0	3000.0
2006	1	500.0	500.0	2000.0
2006	2	500.0	500.0	2000.0
2006	3	500.0	500.0	2000.0
2006	4	500.0	500.0	2000.0
2006	5	500.0	500.0	2000.0
2006	6	500.0	500.0	2000.0
2006	7	500.0	500.0	2000.0
2006	8	500.0	500.0	2000.0
2006	9	500.0	500.0	2000.0
2006	10	500.0	500.0	2000.0
2006	11	500.0	500.0	2000.0
2006	12	500.0	500.0	2000.0
2007	1	0.0	0.0	0.0
2007	2	0.0	0.0	0.0
2007	3	0.0	0.0	0.0
2007	4	0.0	0.0	0.0
2007	5	0.0	0.0	0.0
2007	6	0.0	0.0	0.0
2007	7	0.0	0.0	0.0
2007	8	0.0	0.0	0.0
2007	9	0.0	0.0	0.0
2007	10	0.0	0.0	0.0
2007	11	0.0	0.0	0.0
2007	12	0.0	0.0	0.0

## WRAP-HYD EVA Output File for Example 12

WRAP-HYD Output File Exam12OUT.EVA

EV	CP-1	2005	1.000	1.000	1.000	-0.500	-0.500	-0.500	0.100	0.100	0.100	0.000	0.000	0.000
EV	CP-1	2006	1.000	1.000	1.000	-0.500	-0.500	-0.500	0.100	0.100	0.100	0.000	0.000	0.000
EV	CP-1	2007	1.000	1.000	1.000	-0.500	-0.500	-0.500	0.100	0.100	0.100	0.000	0.000	0.000

## WRAP-HYD FLO Output File for Example 12

WRAP-HYD Output File Exam12OUT.FLO

IN	CP-1	2005	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
IN	CP-2	2005	1100.0	1100.0	1100.0	1100.0	1100.0	1100.0	900.0	900.0	900.0	1000.0	1000.0	1000.0
IN	CP-3	2005	3100.0	3100.0	3100.0	3100.0	3100.0	3100.0	2900.0	2900.0	2900.0	3000.0	3000.0	3000.0
IN	CP-4	2005	3070.0	3070.0	3070.0	3070.0	3070.0	3070.0	2930.0	2930.0	2930.0	3000.0	3000.0	3000.0
IN	CP-1	2006	710.0	710.0	183.8	0.0	0.0	0.0	1507.5	1522.5	1537.5	13.8	11.2	8.8
IN	CP-2	2006	600.0	600.0	600.0	600.0	600.0	600.0	400.0	400.0	400.0	500.0	500.0	500.0
IN	CP-3	2006	2310.0	2310.0	1783.8	1600.0	1600.0	1600.0	2907.5	2922.5	2937.5	1513.8	1511.2	1508.8
IN	CP-4	2006	2217.0	2217.0	1848.6	1720.0	1720.0	1720.0	2635.2	2645.8	2656.2	1659.6	1657.9	1656.1
IN	CP-1	2007	675.0	200.0	0.0	0.0	0.0	0.0	1005.0	1015.0	1025.0	0.0	0.0	0.0
IN	CP-2	2007	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
IN	CP-3	2007	775.0	300.0	100.0	100.0	100.0	100.0	1005.0	1015.0	1025.0	0.0	0.0	0.0
IN	CP-4	2007	542.5	210.0	70.0	70.0	70.0	70.0	703.5	710.5	717.5	0.0	0.0	0.0

## WRAP-HYD Message HMS File for Example 12

WRAP-HYD MESSAGE FILE

```

*** Starting to read file exam12.HIN
*** JC record was read.
*** Starting to read CP records.
*** Finished reading CP records.
*** Reading EP records.
*** Read one EP record.
*** Finished reading file exam12.HIN
*****
Number of CP, SV/SA, OI, EP, AN, AS, EQ records read from HIN file.
  6 control point CP records
  3 control points with streamflows read as input
  2 control points with evap-precip read as input
  1 evaporation-precipitation combining EP records
  2 streamflow adjustment AS records
*****
*** Starting to read IN and/or EV records in JC(1),JC(2)=2 format.
*** Starting to read EV records from EVA file in JC(2)=2 format.
*** Reordering EV records and multiplying by factors on CP records.
*** Finished reading IN and/or EV records.
*** Starting to read flows and/or evap-precip in columnar format.
*** Starting to read streamflows from FLO file in columnar format.
*** Finished reading flows and/or evap-precip.
*** Starting EP record operations.
*** Finished EP record operations.
*** Starting to adjust flows as specified by AS and/or EQ records.
*** Finished AS and/or EQ record operations
*** Starting to write IN and/or EV records.
*** Finished writing IN and/or EV records.

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

```

### **Example 13**

The river basin configuration is represented by four control points (labeled CP-1, CP-2, CP-3, CP-4) located in series on the same stream. A reservoir with identifier RES-A is located at control point CP-2. A file with filename Exam13.HIN contains:

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

Observed stream flows (*IN* records) are provided in an inflow file with the filename Exam13.FLO. Evaporation and precipitation rates (*EV* records) for the reservoir adjustments are provided in the file Exam13.EVA. *WRAP-HYD* performs the evaporation-precipitation manipulations and stream flow adjustments and writes the resulting net evaporation-precipitation (*EV* records) and naturalized stream flows (*IN* records) to output files with filenames Exam13OUT.EVA and Exam13OUT.FLO. The three input files (root1 of Exam13 and extensions DAT, FLO, and EVA) and two output files (root2 of Exam13OUT and extensions FLO and EVA) are presented on the following pages.

Net evaporation-precipitation data (*EV* records) for control points CP-1 and CP-2 are provided in file Exam13.EVA. An *EP* record in the HIN file specifies that the net evaporation-precipitation depths for CP-2 be computed by averaging the depths at CP-1 and CP-3. The output file Exam13OUT.EVA contains only the *EV* records for CP-1, CP-2, and CP-3.

The stream flows entered in the file Exam13.FLO are adjusted as specified by *AS* records using data from *CI*, *FA*, and *RS/SC/SV/SA* records. All of the *RS* record defaults are adopted for the component adjustments for the effects of the reservoir at CP-2. Each adjustment occurs at a specified control point and all downstream locations. After accumulating all adjustments, any negative stream flows are set to zero with a final *AS* record with negative flow option 2 specified in field 9 and a constant adjustment of zero specified in fields 5 and 11.

### WRAP-HYD Input HIN File for Example 13

```

T1 WRAP-HYD Input File Exam13.DAT
T2 Example 13 from Appendix C of Reference Manual
**
**          1          2          3          4          5          6          7          8          9
**345678901234567890123456789012345678901234567890123456789012345678901234567890123456
**      !      !      !      !      !      !      !      !      !      !      !      !      !      !      !      !
JC 1996   3      2      2      2      1                                2      2
**
CP CP-1      CP-2
CP CP-2      CP-3              0                                NONE    10000
CP CP-3      CP-4
CP CP-4              2                                NONE
**
CI CP-3          20      20      20      20      20      20
CI              -10     -20     -100     50      50      50
**
SV RES-A        0      100     200     400     600     800     1000
SA              0      20      40      80      120     160     200
**
** The net evaporation-precipitation EV records for CP-2 are developed by averaging the
** net evaporation-precipitation depths from EV records for CP-1 and CP-3.
**
EP CP-2      CP-1      1.0      CP-3      1.0
**
** CI record adjustments at CP-3 and downstream control points repeated for each of three years.
**
AS CP-3      1996      1998      3
**
** FA record adjustments at CP-3 and downstream control points for three years.
**
AS CP-3
FA 100      100      100     -100     -100     -100      0      0      0      50      50      50
FA -40      -30      -30      0      20      20      50      50      50      50      80      80
FA 25       0       5       18      12     -18      15      26      19      15      12      20
**
** Reservoir Res-A adjustments at CP-2 and downstream control points for two years.
**
AS CP-2      1997      1998      2
RS RES-A                                800                                800
SC 800      800      800      700      500      500      600      700      800      900      850      800
SC 800      800      800      750      750      750      760      770      780      790      800      800
**
** FA record adjustments at CP-1 and downstream control points for one year.
**
AS CP-1      1997      1997
FA 10       10       10      20      20      20      0      0      0     -10     -30     -20
**
** Any negative streamflows are set to zero with the negative amount subtracted the next-month.
**
AS CP-1      1996      1998      4      0      0      0      1
**
ED

```

### WRAP-HYD EVA Input File for Example 13

```

** WRAP-HYD Input File Exam11.EVA
** Example 13 from Appendix C of WRAP Reference Manual
**
EV CP-1 1996 0.21 -0.12 0.15 -0.12 0.43 0.55 0.17 0.49 0.51 0.42 -0.08 0.13
EV CP-1 1997 0.17 0.21 0.39 0.35 0.48 0.51 0.42 0.22 0.38 0.23 0.12 0.21
EV CP-1 1998 0.34 0.12 0.36 0.38 0.42 0.32 0.24 0.18 0.52 0.46 0.39 0.38
**
EV CP-3 1996 0.10 0.00 0.08 -0.10 0.52 0.41 0.02 0.01 0.25 0.09 0.06 -.05
EV CP-3 1997 0.00 0.06 0.23 0.24 0.42 0.56 0.44 0.30 0.12 0.22 0.12 0.01
EV CP-3 1998 0.12 -0.18 0.15 0.22 0.45 0.18 0.11 0.03 0.36 0.15 0.33 0.26

```

### WRAP-HYD FLO Input File for Example 13

```

** WRAP-HYD Input File Exam13.FLO
** Example 13 from Appendix C of WRAP Reference Manual
**
IN CP-1 1996 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000
IN CP-1 1997 3600 400 20 160 140 50 0 210 1400 2200 3100 3200
IN CP-1 1998 6500 6500 6500 6500 6500 6500 7500 7500 7500 7500 7500 7500
**
IN CP-2 1996 5000 5000 5000 5000 5000 5000 5000 5000 5000 5000 5000 5000
IN CP-2 1997 4200 600 50 250 320 80 10 390 2300 3100 4800 4400
IN CP-2 1998 7100 8200 7000 7200 6900 5500 6700 6500 7300 8100 7900 8300
**
IN CP-3 1996 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000
IN CP-3 1997 5500 650 520 560 520 440 90 520 3500 4200 6500 7500
IN CP-3 1998 7600 9600 8200 8200 7300 7300 7300 7300 8600 8600 8600 8600
**
IN CP-4 1996 8000 8000 8000 8000 8000 8000 8000 8000 8000 8000 8000 8000
IN CP-4 1997 7200 1200 1400 2200 1600 1200 850 1400 5200 5700 7200 9200
IN CP-4 1998 9300 12500 8500 9700 8200 7900 7600 8300 9700 9100 8900 10500

```

### WRAP-HYD FLO Output File for Example 13

```

WRAP-HYD Output File Exam13OUT.FLO
IN CP-1 1996 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0 4000.0
IN CP-1 1997 3610.0 410.0 30.0 180.0 160.0 70.0 0.0 210.0 1400.0 2190.0 3070.0 3180.0
IN CP-1 1998 6500.0 6500.0 6500.0 6500.0 6500.0 6500.0 7500.0 7500.0 7500.0 7500.0 7500.0 7500.0
IN CP-2 1996 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0 5000.0
IN CP-2 1997 4304.4 662.8 160.0 262.2 251.8 207.8 204.7 562.7 2509.5 3319.2 4846.0 4438.9
IN CP-2 1998 7287.2 8321.6 7193.6 7354.6 7134.0 5657.5 6864.0 6641.6 7559.5 8332.9 8150.1 8535.2
IN CP-3 1996 6120.0 6120.0 6120.0 5920.0 5920.0 5920.0 5990.0 5980.0 5900.0 6100.0 6100.0 6100.0
IN CP-3 1997 5584.4 702.8 620.0 592.2 491.8 607.8 324.7 722.7 3659.5 4519.2 6676.0 7668.9
IN CP-3 1998 7832.2 9741.6 8418.6 8392.6 7566.0 7459.5 7469.0 7447.6 8778.5 8897.9 8912.1 8905.2
IN CP-4 1996 8120.0 8120.0 8120.0 7920.0 7920.0 7920.0 7990.0 7980.0 7900.0 8100.0 8100.0 8100.0
IN CP-4 1997 7284.4 1252.8 1500.0 2232.2 1571.8 1367.8 1084.7 1602.7 5359.5 6019.2 7376.0 9368.9
IN CP-4 1998 9532.2 12641.6 8718.6 9892.6 8466.0 8059.5 7769.0 8447.6 9878.5 9397.9 9212.1 10805.2

```

### WRAP-HYD EVA Output File for Example 13

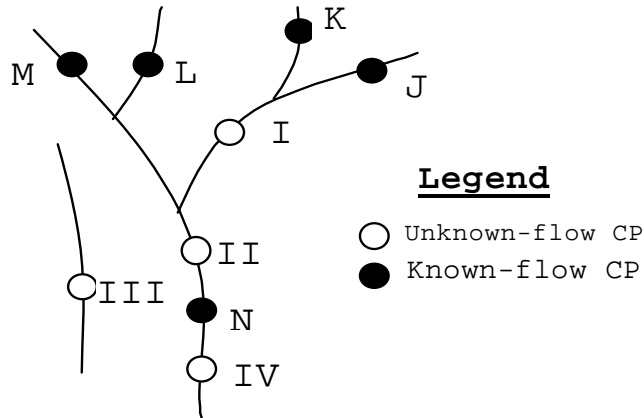
```

WRAP-HYD Output File Exam13OUT.EVA
EV CP-1 1996 0.210 -0.120 0.150 -0.120 0.430 0.550 0.170 0.490 0.510 0.420 -0.080 0.130
EV CP-1 1997 0.170 0.210 0.390 0.350 0.480 0.510 0.420 0.220 0.380 0.230 0.120 0.210
EV CP-1 1998 0.340 0.120 0.360 0.380 0.420 0.320 0.240 0.180 0.520 0.460 0.390 0.380
EV CP-2 1996 0.310 -0.120 0.230 -0.220 0.950 0.960 0.190 0.500 0.760 0.510 -0.020 0.080
EV CP-2 1997 0.170 0.270 0.620 0.590 0.900 1.070 0.860 0.520 0.500 0.450 0.240 0.220
EV CP-2 1998 0.460 -0.060 0.510 0.600 0.870 0.500 0.350 0.210 0.880 0.610 0.720 0.640
EV CP-3 1996 0.100 0.000 0.080 -0.100 0.520 0.410 0.020 0.010 0.250 0.090 0.060 -0.050
EV CP-3 1997 0.000 0.060 0.230 0.240 0.420 0.560 0.440 0.300 0.120 0.220 0.120 0.010
EV CP-3 1998 0.120 -0.180 0.150 0.220 0.450 0.180 0.110 0.030 0.360 0.150 0.330 0.260

```

### Example 14

The system of Figure 4-1 discussed in Chapter 4 is adopted for Example 14. Naturalized flows at gaged control points J, K, L, M, and N, stored in *HYD* input file Exam14.FLO, are used to compute naturalized flows at ungaged control points I, II, III, and IV. The *HYD* input data are provided in files Exam14.HIN, Exam14.FLO, and Exam14.DIS. The output file created by *WRAP-HYD* includes *IN* records for all nine control points. The stream flow input file is shown alternatively as an FLO file in standard format and as a file with filename Exam14.HYD in the optional six flows per record format that also contains evaporation-precipitation depths.



**System Schematic for Example 14**

### **WRAP-HYD Input HIN File for Example 14**

```

** WRAP-HYD Input File Exam14.HIN
** Example 14 from Appendix C of Reference Manual
**
**          1          2          3          4          5          6          7
**3456789012345678901234567890123456789012345678901234567890123456789012
**      !      !      !      !      !      !      !      !      !      !      !      !
** JC record corresponding to use of the input file Exam14.FLO.
**JC 2006  2  1  1  0          1  1  0  3
** Alternative JC record for the alternative input file Exam14.HYD.
JC 2006  2  1  3  3          1  1  1  3
**
CP  CP-J    CP-I      0      0      0
CP  CP-K    CP-I      0      0      0
CP  CP-L    CP-II     0      0  2  0          NONE
CP  CP-M    CP-II     0      0      0
CP  CP-N    CP-IV     0      0      0          0.40
CP  CP-I    CP-II     0      0  2  4          NONE
CP  CP-II   CP-N      0      0  2  8          NONE          0.25
CPCP-III   OUT       0      0  2  3          NONE
CP  CP-IV   OUT       0      0  2  4          NONE
**      !      !      !      !      !      !      !      !      !      !      !      !
ED

```



## WRAP-HYD FLO Input File for Example 14

```

** WRAP-HYD Input File Exam14.FLO
** Example 14 from Appendix C of Reference Manual
**
IN CP-J 2006 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000 4000
IN CP-K 2006 5000 5000 5000 5000 5000 5000 5000 5200 5200 5200 5200 5200 5200
IN CP-L 2006 6500 6500 6500 6500 6500 6500 6500 7500 7500 7500 7500 7500 7500
IN CP-M 2006 6000 6000 6000 6000 6000 6000 6000 8000 8000 8000 8000 8000 8000
IN CP-N 2006 50000 50000 50000 50000 50000 50000 50000 50000 50000 50000 50000 50000 50000
**
IN CP-J 2007 4000 400 40 0 80 500 1000 2000 3000 4000 5000 6000
IN CP-K 2007 5000 500 50 0 90 1000 5200 5200 5200 5200 5200
IN CP-L 2007 6500 650 500 0 500 500 7500 7500 7500 7500 7500
IN CP-M 2007 6000 600 60 0 100 900 8000 8000 8000 8000 8000
IN CP-N 2007 50000 5000 500 0 500 100 100000 0 0 100 8000 50000

```

## WRAP-HYD HYD Input File for Example 14

(File Exam14.HYD may be used as an alternative to FLO and/or EVA files.)

```

** WRAP-HYD Input File Exam14.HYD
** Example 14 from Appendix C of Reference Manual
** Inflow IN and evaporation EV records in
** the optional HYD file format.
**
IN CP-J 2006 4000 4000 4000 4000 4000 4000
IN CP-K 2006 5000 5000 5000 5000 5000 5000
IN CP-L 2006 6500 6500 6500 6500 6500 6500
IN CP-M 2006 6000 6000 6000 6000 6000 6000
IN CP-N 2006 50000 50000 50000 50000 50000 50000
EV CP-J 2006 0.5 0.5 0.5 0.5 0.5 0.5
EV CP-K 2006 0.1 0.1 0.1 0.1 0.1 0.1
EV CP-M 2006 0.40 0.40 0.40 0.40 0.40 0.40
EV CP-N 2006 0.68 0.68 0.68 0.68 0.68 0.68
EV CP-J 2007 0.333 0.333 0.333 0.333 0.333 0.333
IN CP-J 2007 4000 400 40 0 80 500
IN CP-K 2007 5000 500 50 0 90 1000
IN CP-L 2007 6500 650 500 0 500 500
IN CP-M 2007 6000 600 60 0 100 900
IN CP-N 2007 50000 5000 500 0 500 100
IN CP-J 2007 100000 0 0 100 8000 50000
EV CP-J 2007 0.5 0.5 0.5 0.5 0.5 0.5
EV CP-K 2007 0.1 0.1 0.1 0.1 0.1 0.1
EV CP-M 2007 0.40 0.40 0.40 0.40 0.40 0.40
EV CP-N 2007 0.68 0.68 0.68 0.68 0.68 0.68
EV CP-J 2007 0.333 0.333 0.333 0.333 0.333 0.333

```

## WRAP-HYD DIS Input File for Example 14

```

** WRAP-HYD Input File Exam14.DIS
** Example 14 from Appendix C of Reference Manual
**
** Flow distribution FD records
**
FD CP-I      CP-N      2      CP-J      CP-K      CP-L      CP-M
FD CP-II     CP-N      4      CP-J      CP-K      CP-L      CP-M
FD CP-III    CP-N      0      CP-J      CP-K      CP-L      CP-M
FC 0.509
FD CP-IV     CP-N     -1
**
** Watershed parameter WP records
**
WP CP-J      60.      80      30.
WP CP-K      75.      76      30.
WP CP-L     100.      78      31.
WP CP-M      90.      75      31.
WP CP-N     600.      79      31.
WP CP-I     225.      77      31.
WP CP-II    500.      78      31.
WPCP-III    140.      72      32.
WP CP-IV    800      78      31
ED

```

## WRAP-HYD Output HOT File for Example 14

WRAP-HYD Output File Exam14out.OUT

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

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

Watershed Parameters from WP Records

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

## WRAP-HYD FLO Output File for Example 14

WRAP-HYD Output File exam14OUT.FLO

IN	CP-J	2006	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0
IN	CP-K	2006	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5200.0	5200.0	5200.0	5200.0	5200.0	5200.0
IN	CP-L	2006	6500.0	6500.0	6500.0	6500.0	6500.0	6500.0	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0
IN	CP-M	2006	6000.0	6000.0	6000.0	6000.0	6000.0	6000.0	8000.0	8000.0	8000.0	8000.0	8000.0	8000.0
IN	CP-N	2006	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0	50000.0
IN	CP-I	2006	18513.9	18513.9	18513.9	18513.9	18513.9	18513.9	17970.6	17970.6	17970.6	17970.6	17970.6	17970.6
IN	CP-II	2006	45901.7	45901.7	45901.7	45901.7	45901.7	45901.7	47317.4	47317.4	47317.4	47317.4	47317.4	47317.4
INCP-III		2006	17242.4	17242.4	17242.4	17242.4	17242.4	17242.4	16020.8	16020.8	16020.8	16020.8	16020.8	16020.8
IN	CP-IV	2006	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1	43852.1
IN	CP-J	2007	4000.0	400.0	40.0	0.0	80.0	500.0	1000.0	2000.0	3000.0	4000.0	5000.0	6000.0
IN	CP-K	2007	5000.0	500.0	50.0	0.0	90.0	1000.0	5200.0	5200.0	5200.0	5200.0	5200.0	5200.0
IN	CP-L	2007	6500.0	650.0	500.0	0.0	500.0	500.0	7500.0	7500.0	7500.0	7500.0	7500.0	7500.0
IN	CP-M	2007	6000.0	600.0	60.0	0.0	100.0	900.0	8000.0	8000.0	8000.0	8000.0	8000.0	8000.0
IN	CP-N	2007	50000.0	5000.0	500.0	0.0	500.0	100.0100000.0	0.0	0.0	100.0	8000.0	50000.0	0.0
IN	CP-I	2007	18513.9	1536.5	90.0	0.0	170.0	100.0	31671.0	0.0	0.0	100.0	8000.0	19508.1
IN	CP-II	2007	45901.7	4319.0	650.0	0.0	711.4	1329.7	83526.7	9816.2	10248.6	10756.8	17167.6	48203.6
INCP-III		2007	17242.4	1724.2	6.4	0.0	0.0	0.0	42616.0	0.0	0.0	0.0	0.0	15257.3
IN	CP-IV	2007	43852.1	3953.2	318.4	0.0	318.4	60.0	89383.7	0.0	0.0	60.0	6506.8	43852.1

## WRAP-HYD EVA Output File for Example 14

(This EVA file is created with the Exam14.HYD Input File  
and associated version of the JC record.)

WRAP-HYD Output File exam14OUT.EVA

EV	CP-J	2006	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
EV	CP-K	2006	0.100	0.100	0.100	0.100	0.100	0.100	0.250	0.250	0.250	0.250	0.250	0.250
EV	CP-M	2006	0.400	0.400	0.400	0.400	0.400	0.400	0.680	0.680	0.680	0.680	0.680	0.680
EV	CP-N	2006	0.210	0.210	0.210	0.210	0.210	0.210	0.333	0.333	0.333	0.333	0.333	0.333
EV	CP-J	2007	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
EV	CP-K	2007	0.100	0.100	0.100	0.100	0.100	0.100	0.250	0.250	0.250	0.250	0.250	0.250
EV	CP-M	2007	0.400	0.400	0.400	0.400	0.400	0.400	0.680	0.680	0.680	0.680	0.680	0.680
EV	CP-N	2007	0.210	0.210	0.210	0.210	0.210	0.210	0.333	0.333	0.333	0.333	0.333	0.333

## Example 15

Example 15 consists of converting regulated flows read from the *SIM* output OUT file for Example 6 to *IN* records written to a *HYD* output HOT file. Example 6 must be run to create the OUT file. The *IN* record dataset can be used as the FLO input file for either *SIM* or *HYD*.

### WRAP-HYD Input HIN File for Example 15

```
** WRAP-HYD Input File Exam15.HIN
** Example 15 from Appendix C of Reference Manual
** Regulated flows read from the OUT file of
** Example 6 are converted to IN records.
**
**      1      2
**345678901234567890
**      !      !      !      !
JC 1997      2      1      7
**
OI      2      2      IN
**
ED
```

### WRAP-HYD Output HOT File for Example 15

WRAP-HYD Output File Exam15OUT.HOT

IN	CP1	1997	20.0	20.0	20.0	20.0	36.1	50.5	74.6	23.8	0.0	0.0	0.0	0.0
IN	CP1	1998	7.2	7.2	14.4	128.5	260.0	260.0	74.6	65.2	0.0	0.0	0.0	0.0
IN	CP2	1997	0.0	0.0	0.0	14.4	19.1	67.0	0.0	11.3	0.0	0.0	0.0	0.0
IN	CP2	1998	0.0	0.0	0.0	0.0	0.0	0.0	16.6	62.4	52.4	0.0	0.0	0.0
IN	CP3	1997	25.8	25.8	18.6	13.0	29.6	77.5	13.0	10.0	10.0	10.0	10.0	10.0
IN	CP3	1998	12.9	13.0	13.0	187.1	314.4	300.0	29.6	73.3	10.0	10.0	10.0	10.0
IN	CP4	1997	6.0	6.0	1.7	16.1	100.0	100.0	100.0	84.0	0.0	0.0	0.0	0.0
IN	CP4	1998	0.0	0.0	0.0	0.0	408.3	403.8	100.0	100.0	0.0	0.0	0.0	0.0
IN	CP5	1997	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN	CP5	1998	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IN	CP6	1997	48.1	48.1	43.8	88.2	60.0	60.0	10.0	10.0	53.4	23.3	23.3	23.3
IN	CP6	1998	48.7	48.8	51.7	323.3	608.3	603.8	10.0	10.0	10.0	29.7	31.6	34.1

### WRAP-HYD Message HMS File for Example 15

WRAP-HYD MESSAGE FILE

```
*** Starting to read file Exam15.HIN
*** JC record was read.
*** Finished reading file Exam15.HIN
*****
Number of CP, SV/SA, OI, EP, AN, AS, EQ records read from HIN file.
  0 control point CP records
  0 control points with streamflows read as input
  0 control points with evap-precip read as input
  1 OUT input file OI records
*****
*** Starting OUT file operations.
*** Finished OUT file operations.

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