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Water Rights Analysis Package (WRAP) Modeling System Reference Manual

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Texas Water Resources Institute
make every drop count

Water Rights Analysis Package (WRAP) Modeling System

Reference Manual

by

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for the

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ACKNOWLEDGEMENTS

Development of WRAP has progressed since 1986 under the auspices of several sponsors, primarily the Texas Commission on Environmental Quality (TCEQ). 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 began in 1996 before the 1997 Senate Bill 1. The TNRCC was renamed the Texas Commission on Environmental Quality in 2002. WRAP 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 modeling system has continued to be expanded and improved during 2005-2013 under the auspices of the TCEQ. The U.S. Army Corps of Engineers Fort Worth District during 2001-2005 also sponsored continued development of modeling capabilities. The TWDB sponsored additional improvements during 2007-2008. The Brazos River Authority also sponsored additional improvements during 2008-2011.

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 model 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 and undergraduate students at Texas A&M University have used WRAP in courses and research projects. The former graduate students acknowledged here made significant contributions to development of the modeling system working as funded research assistants and focusing their thesis or dissertation research on WRAP related topics. 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; Ganesh Krishnamurthy, M.S. 2005; Miae Ha, M.S. 2006; Tae Jin Kim, Ph.D. 2009; Spencer T. Schnier, M.S. 2010; Chihun Lee, Ph.D. 2010, and Richard J. Hoffpauir, Ph.D. 2010. 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. Dr. Richard Hoffpauir has worked for over ten years both as a researcher expanding WRAP capabilities and as a consultant applying the modeling system and is currently continuing development of expanded WRAP modeling capabilities.

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 applications outside of Texas, model users must develop their own input datasets.

WRAP Documentation

WRAP is documented by this *Reference Manual* and companion *Users Manual*, an introductory *Fundamentals Manual*, and the following auxiliary manuals that cover specific aspects of the modeling system that are not covered in the basic *Reference and Users Manuals*.

Water Rights Analysis Package (WRAP) Modeling System Reference and Users Manuals, TWRI TR-255 and TR-266, Ninth Edition, August 2012.

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

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

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

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

Water Rights Analysis Package (WRAP) Programming Manual, TWRI TR-388, 2nd Edition, August 2012. (*Programming 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 two primary manuals cover the WRAP modeling features reflected in the original and updated 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*, *Daily*, *Hydrology*, and *Salinity Manuals*. However, easy-to-learn fundamentals covered in the *Fundamentals Manual* account for a significant portion of practical modeling applications.

The *Reference*, *Users*, and *Fundamental Manuals* describe the monthly *SIM* simulation model and corresponding features of the post-simulation program *TABLES*. The *Daily Manual* describes *SIMD* which provides sub-monthly (daily) simulation capabilities, that include pulse environmental flow requirements and flood control reservoir operations, and corresponding daily features of *TABLES*. The *Hydrology Manual* documents capabilities provided by program *HYD* to develop and update monthly naturalized stream flow and net reservoir surface evaporation-precipitation sequences for input to *SIM*. The *Salinity Manual* covers the salinity tracking capabilities of *SALT* and salinity-related features of *TABLES*. The *Programming Manual* facilitates maintaining the Fortran programs but is not needed for applying modeling system.

Texas Water Resources Institute (TWRI) technical reports TR-340 (Wurbs and Kim 2008), TR-352 (Wurbs and Lee 2009), and TR-389 (Wurbs, Hoffpauir, and Schnier 2012) present case study applications of WRAP features not yet routinely applied in the WAM System. A state-of-the-art review of reservoir/river system modeling capabilities is presented in TR-282 (Wurbs 2005). TWRI reports are available at: http://twri.tamu.edu/publications/reports

WRAP Programs

WRAP is a set of computer programs. Executable files are available for use with Microsoft Windows. The Fortran programs have been compiled with the Intel Visual Fortran compiler 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 is 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 auxiliary manuals covering expanded modeling capabilities.

Table 1.1
WRAP Programs

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

The following programs supplement and/or expand the programs listed above. The following programs are not covered in the basic *Reference and Users Manuals* and *Fundamentals Manual* but rather are documented by the auxiliary manuals noted in Table 1.1.

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

SIMD (*D* for daily) is an expanded version of *SIM* that includes features for sub-monthly time steps, flow disaggregation, flow forecasting and routing, pulse flows, 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 without using *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 routing, and simulating pulse environmental flows and 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 *SIMD* daily or other sub-monthly time step, disaggregation of monthly to daily naturalized flows, daily water use target setting, pulse environmental flow targets, flow forecasting, flow routing, and flood control reservoir operations features covered in the *Daily 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, flood control, and other multiple-purpose reservoir system operating decisions. Routing methodologies model translation and attenuation of stream flow adjustments. The post-simulation program *TABLES* works with either monthly or sub-monthly (daily) *SIM/SIMD* simulation results.

HYD and DAY Pre-Simulation Hydrology Programs

Program *HYD* described in the *Hydrology Manual* provides routines for developing and updating hydrology input for *SIM*, which consists of sequences of monthly naturalized stream flows and reservoir net evaporation-precipitation rates. *HYD* can be used both in developing new hydrology datasets and updating the hydrologic period-of-analysis covering by existing datasets.

The program *DAY* documented in the *Daily Manual* provides a set of computational routines that facilitate developing *SIMD* hydrology input related to daily 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 and NotePad++

Notepad++ described in Chapter 6 and Microsoft Word, Wordpad, and Notepad are used routinely in creating and editing WRAP input files and viewing simulation results. Microsoft 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. Data can be conveniently transported between Microsoft Excel and HEC-DSS.

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 2009). 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. The HEC-SSP Statistical Software Package (Hydrologic Engineering Center 2009) is another companion program that can be useful with the WRAP programs.

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.crwr.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 further noted in the following section on pages 7-8.

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 75th 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; Wurbs 2005; Martin and Chenoweth 2009). 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 2005-2012 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. The WRAP input datasets for all of the Texas river basins are publicly 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, 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 scenario datasets as of July 2011 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.

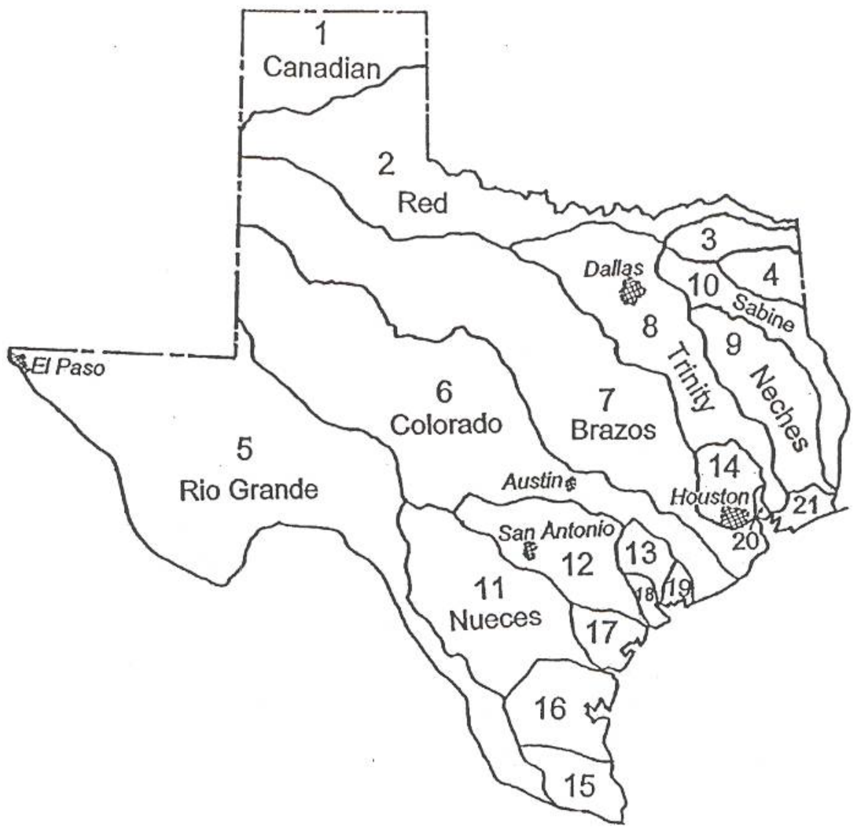

Figure 1.1 Texas WAM System River Basins

The 21 authorized use datasets as of July 2011 contained 10,361 water right *WR* records and 697 instream flow *IF* records (11,058 total model water rights) representing about 8,000 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 13,229 control points, including 499 primary control points, usually representing gaging stations, with naturalized flows included in the WRAP-SIM input. The datasets model the approximately 3,449 reservoirs for which a water right permit has been issued. Over 90 percent of the total capacity of the 3,449 reservoirs is contained in the approximately 200 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 Primary Control Points	Number of Total Control Points	Number of WR Record Rights	Number of IF Record Rights	Number of Model Reser-voirs	Reservoir Storage Capacity (acre-feet)	Mean Natural Flow (ac-ft/yr)
1	Canadian River Basin	1948-98	12	85	56	0	47	966,000	190,000
2	Red River Basin	1948-98	47	447	494	101	245	4,124,000	11,049,000
3	Sulphur River Basin	1940-96	8	83	85	10	57	753,000	2,498,000
4	Cypress Bayou Basin	1948-98	10	147	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	3,842	1,634	122	678	4,695,000	6,357,000
8	Trinity River Basin	1940-96	40	1,343	1,027	35	700	7,504,000	6,879,000
9	Neches River Basin	1940-96	20	306	328	19	180	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	1,338	848	200	238	808,000	2,101,000
13	Lavaca River Basin	1940-96	7	185	72	30	22	235,000	943,000
14	San Jacinto River Basin	1940-96	17	412	150	15	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
	Total		499	13,229	10,361	697	3,449	60,834,290	56,905,000

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).

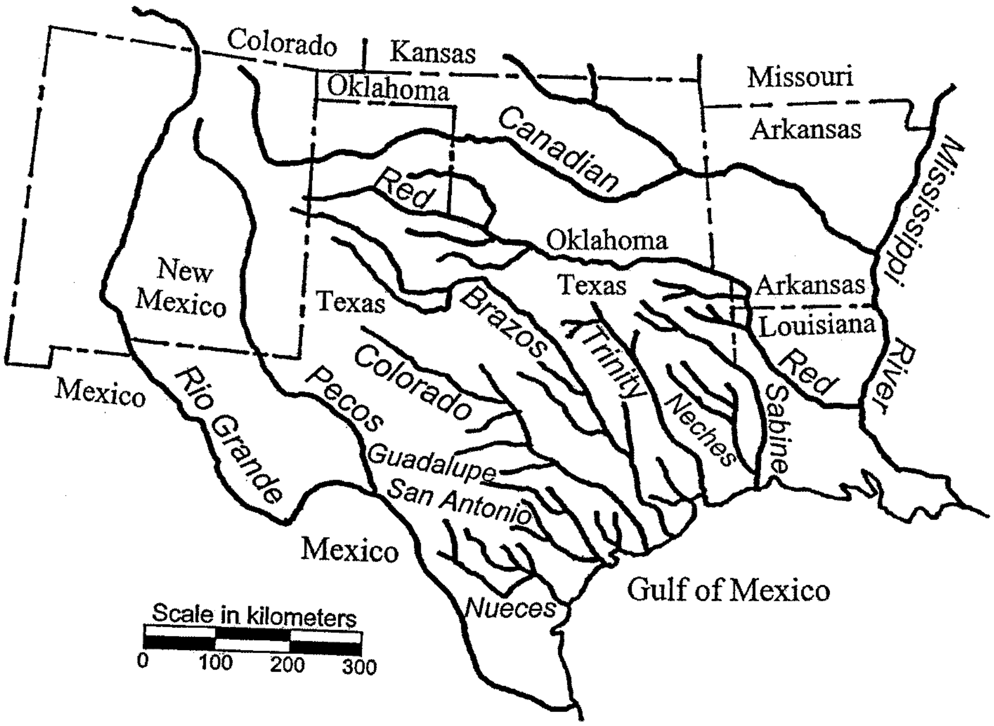

Figure 1.2 Major Rivers of Texas

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 groups, 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 modeling system 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 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).

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 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 supply reliabilities (Wurbs *et al*. 1994; Sanchez-Torres 1994). 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 (Wurbs 2009). Whereas the original *WRAP-SALT* integrated the salinity computations internally within *WRAP3* creating a separate program, the current *SALT* is a companion program that reads a *SIM* output file along with a salinity input 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 2005-2012 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 Corps of Engineers Fort Worth District 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 that have been routinely applied for some time. The following additional major new modeling capabilities are, as of August 2012, just now being implemented for routine application.

Short-term 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. Routing methods model flow translation and attenuation. Routing parameter calibration methods are provided. Future time steps extending over a forecast period are considered in determining water availability and flood flow capacities. Daily target setting features include pulse environmental flows. *TABLES* develops frequency relationships and reliability indices reflecting the dail 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 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 specific additional modeling capabilities covered by the *Daily*, *Hydrology*, and *Salinity Manuals*. The selected features described in the *Fundamentals Manual* are covered in much greater detail in the *Reference* and *Users Manuals.* The *Programming Manual* documenting the Fortran code for all of 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, 2, and 8 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. Chapter 8 discusses aids for correcting input errors. Appendix A is a glossary of terms used in the manuals. A list of references is provided on pages 295-297.

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. Short-term conditional reliability modeling (CRM) is covered in Chapter 7 along with three CRM examples that built upon the example in the *Fundamentals Manual*.

Appendix B consists of *SIM* and *TABLES* examples that provide simple datasets with easy-to-track numbers to which additional modeling options of interest can be added to explore their functionality. Computations can be readily tracked by examining simulation results. Input files for all examples in all manuals are available in electronic format along with the executable programs.

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, Iterative Firm Yield, and Short-Term 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 firm yield 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 is explained in Chapter 7.

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. Figure 2.1 below is a schematic of a river system modeled as a set of 18 control points with reservoirs located at eight of the control points. 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.

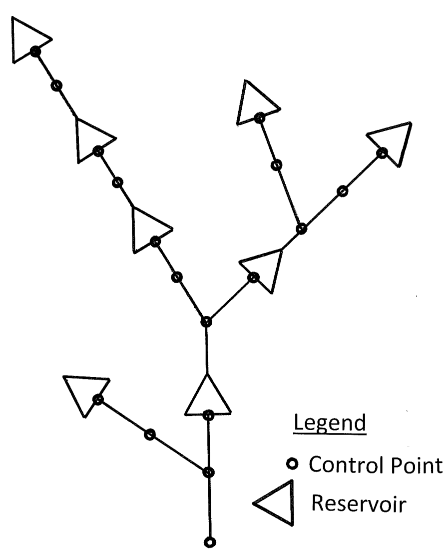

Figure 2.1 Reservoir/River System Schematic

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 ungaged sites for which flows are computed within *SIM* are called *secondary* control points. Options for distributing naturalized flows from gaged to ungaged 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

WR 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 contents volume
available stream flow	available stream flow	unappropriated flow	storage capacity volume
stream flow depletion	stream flow depletion	stream flow depletion	evap-precip volume
reservoir releases	required res release	naturalized flow	evap-precip depth
return flow	reservoir release	regulated flow	adjusted evap-prec depth
available flow increase	reservoir release shortage	reservoir releases	reservoir inflow
water right identifier	flow switch volume	return flow	reservoir release
first group identifier	flow switch count	channel loss	turbine flow
second group identifier	water right identifier	channel loss credit	water surface elevation
		instream flow target	reservoir 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^2 = million m^3) 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*, 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	*SIM*	*TABLES*
Explanation of model capabilities and methods	RM Ch 2-6, 7	RM Ch 2,5,6,7
Detailed instructions for preparing input data	UM Ch 2 and 3	UM Chap 4
Example datasets	RM Appd B	RM Appd B
	and Fundamentals Manual	
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 *Daily 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 Water Right Identifier	2 Control Point	3 Priority Number	4 Target Diversion (ac-ft/mon)	5 Reservoir Capacity (acre-feet)	6 Initial Storage (acre-feet)
WR-A	CP-4	1954	15	200	195
WR-B	CP-1	1972	10	-	-
WR-C	CP-2	1999	40	-	-

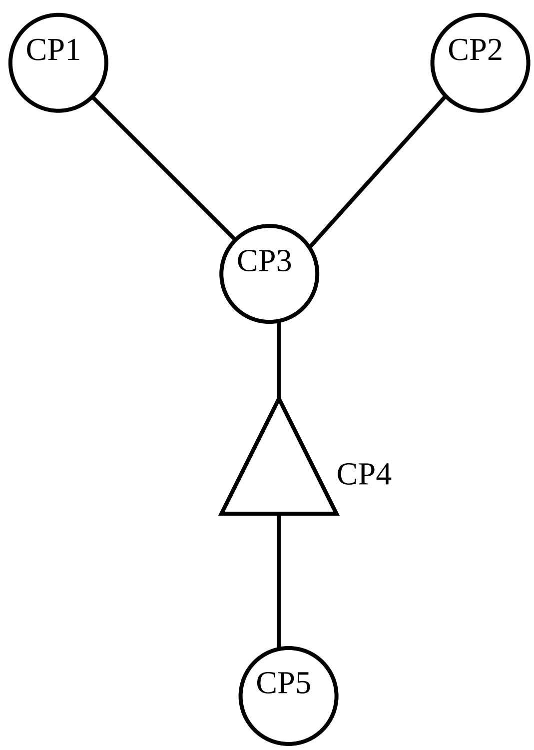

Figure 2.3 Control Point Schematic for Example 1

Table 2.4 Water Rights Simulation Results for Example 1

1 Water Right Identifier	2 Control Point	3 Available Streamflow (acre-feet)	4 Reservoir Evap- Prec (acre-feet)	5 End Month Storage (acre-feet)	6 Target Diversion (acre-feet)	7 Actual Diversion (acre-feet)	8 Diversion Shortage (acre-feet)	9 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
		After WR-A		*After WR-B*		*After WR-C*	
Control Point Identifier	Naturalized Flow (acre-feet)	CP Flow (acre-feet)	Available Flow (acre-feet)	CP Flow (acre-feet)	Available Flow (acre-feet)	Regulated Flow (acre-feet)	Unappro-priated Flow (acre-feet)
CP-1	20	20	20	10	10	10	0
CP-2	45	45	40	45	30	15	0
CP-3	70	70	40	60	30	30	0
CP-4	80	40	40	30	30	0	0
CP-5	100	60	60	50	50	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:

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

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 54 *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 36 month 2005-2007 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 twelve months of the simulation results are included in Table 2.8. *TABLES* input and output files (filenames Tab2.TIN and Tab2.TOU) 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 *TABLES* 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.TOU) 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, with identifiers CP1 and CP2. Information describing this system is contained in the *SIM* input file with filename Exam2.DAT reproduced as Table 2.6.

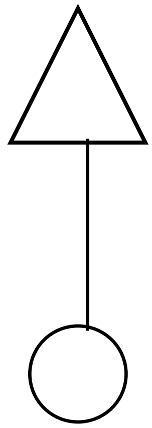

Figure 2.4 Control Point Schematic for Example 2

Of the three water rights, the environmental instream flow requirement of 1,000 acre-feet/month at control point 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 use coefficients entered on *UC* records that are connected to *WR* and *IF* records by use identifiers. The default is a constant uniform distribution.

The next-month return flow option is adopted for the right with identifier Municipal Right. A return flow of 40 percent of the diversion occurring at control point CP1 is returned at CP2 in the next month following the diversion. Return flows are incorporated in the available stream flows at control point CP2 at the beginning of the priority sequence in the next month of the simulation.

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 to convert the evaporation-precipitation depths to feet. A storage (acre-feet) versus water surface area (acres) relationship for reservoir Res-A is defined by *SV/SA* records.

The system is simulated with *SIM*, and the simulation results are organized using program *TABLES*. The *TABLES* input file (filename Exam2.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 Exam2.OUT, which is reproduced as Table 2.9. The tables shown in Table 2.9 illustrate some of the types and variations of tables that may be created by *TABLES* to organize, summarize, and analyze simulation results.

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
**       1         2         3         4         5         6         7         8         9        10        11
**34567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
**     !       !       !       !       !       !       !       !       !       !       !       !       !       !
JD     3    2005       1      -1      -1
JO     3
**
UC munic    0.06    0.06    0.07    0.07    0.08    0.10    0.13    0.12    0.09    0.08    0.08    0.06
UC irrig    0.00    0.00    0.04    0.12    0.19    0.22    0.22    0.15    0.05    0.01    0.00    0.00
**
CP   CP1     CP2         0.08333
CP   CP2     OUT                                    none
**
IF   CP2   12000               1                   Instream Flow
WR   CP2   38000   irrig       3                                Irrigation Right
WR   CP1   96000   munic       2       2     0.4                 Municipal Right
WS Res-A  110000
**
SV Res-A       0    1030    3730   10800   27700   53400   92100  112000
SA             0     140     409    1150    2210    3100    4690    6160
ED
IN   CP1    2005   10200    6540    3710    7350   15100     904     112     328     972    2650   17300    1290
IN   CP2    2005   12700    7660    4760    9190   21400    1130     145     447    1220    3310   21800    1620
EV   CP1    2005     3.7     3.9     3.9     3.8     4.2     4.5     4.6     4.3     4.1     3.9       4     3.9
**
IN   CP1    2006    3390    3110   12900   42300   62700   76500   16900   21200   25700    8810    1560    1850
IN   CP2    2006    4160    3780   15800   51600   78000   96800   21200   26500   31400   11900    1930    2310
EV   CP1    2006     3.6     3.7     3.8     3.6     4.1     4.3     4.4     4.2       4     3.7     3.9     3.7
**
IN   CP1    2007    3290    8970    1570    2410   48900    5630    7990    3910    1090    1740   13700   14600
IN   CP2    2007    4090   11200    2140    3210   59300    7160   10060    4950    1380    2320   17100   18300
EV   CP1    2007     3.8     3.9     4.0     3.8     4.1     4.2     4.3     4.4     4.2     3.7     4.1     3.7
```

Table 2.7

TABLES Input File for Example 2

```
COMM   Example 2 - TABLES Input File Exam2.TIN
**       1         2         3         4         5
**  5678901234567890123456789012345678901234567890123456
**     !   !   !   !   !   !   !   !   !   !   !   !   !
2SCP
2REL
2FRE   2
2FRQ   2   0   4     CP2    1000    2000    5000   10000
2STO   1   1   1   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
IDENIrrigation Right
ENDF
```

Table 2.8
First Year of SIM Output File for Example 2

```
WRAP-SIM (August 2012 Version) OUT Output File
 Example 2 - WRAP-SIM Input File Exam2.DAT
 Example 2 from Chapter 2 of the Reference Manual

  2005    3    2    3    0    0    0    0  1.000
IF   1      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
2005 1     0.000  5760.000   1853.71 110000.00   7613.71  10200.00      0.00 Municipal Right                2304.00      0.00
2005 1     0.000     0.000      0.00      0.00      0.00   4086.29      0.00Irrigation Right                  0.00      0.00
  CP1      0.000  5760.000   1853.71 110000.00   7613.71   2586.29      0.00  10200.00   2586.29     0.    0.     0.     0.0
  CP2      0.000     0.000      0.00      0.00      0.00   4086.29      0.00  12700.00   5086.29     0.    0.     0.  1000.0
IF   2      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
2005 2     0.000  5760.000   1939.98 108840.02   6540.00   6540.00      0.00 Municipal Right                2304.00      0.00
2005 2     0.000     0.000      0.00      0.00      0.00   2424.00      0.00Irrigation Right                  0.00      0.00
  CP1      0.000  5760.000   1939.98 108840.02   6540.00      0.00      0.00   6540.00      0.00     0.    0.     0.     0.0
  CP2      0.000     0.000      0.00      0.00      0.00   2424.00   2304.00   7660.00   3424.00     0.    0.     0.  1000.0
IF   3      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
2005 3     0.000  6720.000   1867.51 103962.50   3710.00   3710.00      0.00 Municipal Right                2688.00      0.00
2005 3     0.000  1520.000      0.00      0.00   1520.00   2354.00      0.00Irrigation Right                  0.00      0.00
  CP1      0.000  6720.000   1867.51 103962.50   3710.00      0.00      0.00   3710.00      0.00     0.    0.     0.     0.0
  CP2      0.000  1520.000      0.00      0.00   1520.00    834.00   2304.00   4760.00   1834.00     0.    0.     0.  1000.0
IF   4      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
2005 4     0.000  6720.000   1749.49 102843.01   7350.00   7350.00      0.00 Municipal Right                2688.00      0.00
2005 4  1032.000  4560.000      0.00      0.00   3528.00   3528.00      0.00Irrigation Right                  0.00      0.00
  CP1      0.000  6720.000   1749.49 102843.01   7350.00      0.00      0.00   7350.00      0.00     0.    0.     0.     0.0
  CP2   1032.000  4560.000      0.00      0.00   3528.00      0.00   2688.00   9190.00   1000.00     0.    0.     0.  1000.0
IF   5      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
2005 5     0.000  7680.000   1989.38 108273.63  15100.00  15100.00      0.00 Municipal Right                3072.00      0.00
2005 5     0.000  7220.000      0.00      0.00   7220.00   7988.00      0.00Irrigation Right                  0.00      0.00
  CP1      0.000  7680.000   1989.38 108273.63  15100.00      0.00      0.00  15100.00      0.00     0.    0.     0.     0.0
  CP2      0.000  7220.000      0.00      0.00   7220.00    768.00   2688.00  21400.00   1768.00     0.    0.     0.  1000.0
IF   6      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
2005 6     0.000  9600.000   2057.75  97519.88    904.00    904.00      0.00 Municipal Right                3840.00      0.00
2005 6  6062.000  8360.000      0.00      0.00   2298.00   2298.00      0.00Irrigation Right                  0.00      0.00
  CP1      0.000  9600.000   2057.75  97519.88    904.00      0.00      0.00    904.00      0.00     0.    0.     0.     0.0
  CP2   6062.000  8360.000      0.00      0.00   2298.00      0.00   3072.00   1130.00   1000.00     0.    0.     0.  1000.0
IF   7      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
2005 7     0.000 12480.000   1805.56  83346.32    112.00    112.00      0.00 Municipal Right                4992.00      0.00
2005 7  5487.000  8360.000      0.00      0.00   2873.00   2873.00      0.00Irrigation Right                  0.00      0.00
  CP1      0.000 12480.000   1805.56  83346.32    112.00      0.00      0.00    112.00      0.00     0.    0.     0.     0.0
  CP2   5487.000  8360.000      0.00      0.00   2873.00      0.00   3840.00    145.00   1000.00     0.    0.     0.  1000.0
IF   8      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
2005 8     0.000 11520.000   1458.53  70695.79    328.00    328.00      0.00 Municipal Right                4608.00      0.00
2005 8  1589.000  5700.000      0.00      0.00   4111.00   4111.00      0.00Irrigation Right                  0.00      0.00
  CP1      0.000 11520.000   1458.53  70695.79    328.00      0.00      0.00    328.00      0.00     0.    0.     0.     0.0
  CP2   1589.000  5700.000      0.00      0.00   4111.00      0.00   4992.00    447.00   1000.00     0.    0.     0.  1000.0
IF   9      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
2005 9     0.000  8640.000   1239.39  61788.40    972.00    972.00      0.00 Municipal Right                3456.00      0.00
2005 9     0.000  1900.000      0.00      0.00   1900.00   3856.00      0.00Irrigation Right                  0.00      0.00
  CP1      0.000  8640.000   1239.39  61788.40    972.00      0.00      0.00    972.00      0.00     0.    0.     0.     0.0
  CP2      0.000  1900.000      0.00      0.00   1900.00   1956.00   4608.00   1220.00   2956.00     0.    0.     0.  1000.0
IF  10      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
200510     0.000  7680.000   1078.68  55679.72   2650.00   2650.00      0.00 Municipal Right                3072.00      0.00
200510     0.000   380.000      0.00      0.00    380.00   3116.00      0.00Irrigation Right                  0.00      0.00
  CP1      0.000  7680.000   1078.68  55679.72   2650.00      0.00      0.00   2650.00      0.00     0.    0.     0.     0.0
  CP2      0.000   380.000      0.00      0.00    380.00   2736.00   3456.00   3310.00   3736.00     0.    0.     0.  1000.0
IF  11      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
200511     0.000  7680.000   1122.70  64177.02  17300.00  17300.00      0.00 Municipal Right                3072.00      0.00
200511     0.000     0.000      0.00      0.00      0.00   6572.00      0.00Irrigation Right                  0.00      0.00
  CP1      0.000  7680.000   1122.70  64177.02  17300.00      0.00      0.00  17300.00      0.00     0.    0.     0.     0.0
  CP2      0.000     0.000      0.00      0.00      0.00   6572.00   3072.00  21800.00   7572.00     0.    0.     0.  1000.0
IF  12      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
200512     0.000  5760.000   1114.08  58592.95   1290.00   1290.00      0.00 Municipal Right                2304.00      0.00
200512     0.000     0.000      0.00      0.00      0.00   2402.00      0.00Irrigation Right                  0.00      0.00
  CP1      0.000  5760.000   1114.08  58592.95   1290.00      0.00      0.00   1290.00      0.00     0.    0.     0.     0.0
  CP2      0.000     0.000      0.00      0.00      0.00   2402.00   3072.00   1620.00   3402.00     0.    0.     0.  1000.0
IF   1      0.00      0.00      0.00      0.00      0.00      0.00      0.00  Instream Flow   1000.00       0.00      0.00  0
2006 1     0.000  5760.000    973.36  55249.58   3390.00   3390.00      0.00 Municipal Right                2304.00      0.00
```

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 2006 at control point CP1:

naturalized streamflow + return flow = storage change + diversion + evaporation + regulated flow

276,920 ac-ft/yr + 0 = (95,820 − 58,593) + 96,000 + 19,679 + 124,014 ac-ft/yr

Stream flow depletions are:

streamflow depletion = diversion + evaporation + storage refilling

CP1 2006 streamflow depletion = 96,000 + 19,679 + (95,820 − 58,593) = 152,906 ac-ft/yr

CP2 2006 streamflow depletion = diversion = 38,000 ac-ft/yr

Since CP2 is the most downstream gage, the 2006 annual volume balance may be expressed as:

naturalized flows + return flows = CP1 and CP2 streamflow depletions + CP2 regulated flows

345,380 + 38,400 = 152,906 + 38,000 + 192,874

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 acre-feet/year diversion target at CP1 has no shortages and thus period and volume reliabilities of 100.0%. The monthly diversion requirements for the 38,000 acre-feet/year 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:

period reliability = [(24−8)/24] 100% = 66.67%

volume reliability = [(38,000−8,372.67)/38,000] 100% = 77.97%

The reliability table shows that the diversion at CP2 equals or exceeds 50 percent of the monthly target in 87.5 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 to 79,758 acre-feet/month, with a mean of 7,666 acre-feet/month. The regulated flow equals or exceeds 1,768 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.

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)
2005	66456.0	2586.3	2586.3	0.0	63869.7	58592.9	19276.8	96000.0	0.0
2006	276920.0	124014.0	122794.0	0.0	152906.0	95819.8	19679.1	96000.0	0.0
2007	113800.0	10579.6	10579.6	0.0	103220.4	84189.6	18850.7	96000.0	0.0
MEAN	152392.0	45726.6	45320.0	0.0	106665.4	79534.1	19268.8	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)
2005	85382.0	33778.3	21778.3	36096.0	23830.0	0.0	0.0	23830.0	14170.0
2006	345380.0	192874.0	180874.0	38400.0	38000.0	0.0	0.0	38000.0	0.0
2007	141210.0	49337.6	37337.6	38400.0	27052.0	0.0	0.0	27052.0	10948.0
MEAN	190657.3	91996.6	79996.6	37632.0	29627.3	0.0	0.0	29627.3	8372.7

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	++++++++ PERCENTAGE OF MONTHS ++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- 100%	98%	95%	90%	75%	50%	1%
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
CP2	38000.0	8372.67	66.67	77.97	66.7	66.7	66.7	75.0	87.5	100.0	100.0	33.3	33.3	33.3	33.3	33.3	100.0	100.0
Total	134000.0	8372.67		93.75														

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP1	3810.6	12261.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	12370.	64746.
CP2	7666.4	14828.	1000.0	1000.0	1000.0	1000.0	1000.0	1768.0	3028.	3424.	3673.	6472.	19254.	79758.

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS FOR CONTROL POINT CP2

FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)	FLOW	FREQ(%)
1000.0	100.00	2000.0	66.67	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	MEAN
2005	110000.0	108840.0	103962.5	102843.0	108273.6	97519.9	83346.3	70695.8	61788.4	55679.7	64177.0	58592.9	85476.6
2006	55249.6	51641.5	56827.2	91223.0	110000.0	110000.0	110000.0	110000.0	110000.0	109284.4	101323.3	95819.8	92614.1
2007	91823.0	93494.0	86799.8	81110.7	110000.0	104003.3	97602.5	88227.5	79157.0	71980.3	76647.6	84189.6	88752.9
MEAN	85690.9	84658.5	82529.8	91725.6	109424.5	103841.1	96982.9	89641.1	83648.5	78981.5	80716.0	79534.1	88947.9

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2005	12700.	7660.	4760.	9190.	21400.	1130.	145.	447.	1220.	3310.	21800.	1620.	85382.
2006	4160.	3780.	15800.	51600.	78000.	96800.	21200.	26500.	31400.	11900.	1930.	2310.	345380.
2007	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
2005	5086.	3424.	1834.	1000.	1768.	1000.	1000.	1000.	2956.	3736.	7572.	3402.	33778.
2006	3074.	2974.	3684.	7428.	45189.	79758.	1996.	12168.	23464.	6166.	3442.	3532.	192874.
2007	3104.	4534.	1354.	1000.	16448.	1000.	1000.	1000.	2998.	3656.	6472.	6772.	49338.
MEAN	3755.	3644.	2291.	3143.	21135.	27253.	1332.	4723.	9806.	4519.	5829.	4569.	91997.

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2005	4086.	2424.	834.	0.	768.	0.	0.	0.	1956.	2736.	6572.	2402.	21778.
2006	2074.	1974.	2684.	6428.	44189.	78758.	996.	11168.	22464.	5166.	2442.	2532.	180874.
2007	2104.	3534.	354.	0.	15448.	0.	0.	0.	1998.	2656.	5472.	5772.	37338.
MEAN	2755.	2644.	1291.	2143.	20135.	26253.	332.	3723.	8806.	3519.	4829.	3569.	79997.

DIVERSIONS (AC-FT) FOR WATER RIGHT Irrigation Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2005	0.00	0.00	1520.00	3528.00	7220.00	2298.00	2873.00	4111.00	1900.00	380.00	0.00	0.00	23830.00
2006	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
2007	0.00	0.00	1520.00	2488.00	7220.00	3602.00	4910.00	5032.00	1900.00	380.00	0.00	0.00	27052.00
MEAN	0.00	0.00	1520.00	3525.33	7220.00	4753.33	5381.00	4947.67	1900.00	380.00	0.00	0.00	29627.33

Table 2.9 (Continued)
TABLES Output File for Example 2

		STO CP1	NAT CP2	REG CP2	UNA CP2	IFS Instream	DIV Irrigati
2005	1	110000.00	12700.00	5086.29	4086.29	0.00	0.00
2005	2	108840.02	7660.00	3424.00	2424.00	0.00	0.00
2005	3	103962.50	4760.00	1834.00	834.00	0.00	1520.00
2005	4	102843.01	9190.00	1000.00	0.00	0.00	3528.00
2005	5	108273.63	21400.00	1768.00	768.00	0.00	7220.00
2005	6	97519.88	1130.00	1000.00	0.00	0.00	2298.00
2005	7	83346.32	145.00	1000.00	0.00	0.00	2873.00
2005	8	70695.79	447.00	1000.00	0.00	0.00	4111.00
2005	9	61788.40	1220.00	2956.00	1956.00	0.00	1900.00
2005	10	55679.72	3310.00	3736.00	2736.00	0.00	380.00
2005	11	64177.02	21800.00	7572.00	6572.00	0.00	0.00
2005	12	58592.95	1620.00	3402.00	2402.00	0.00	0.00
2006	1	55249.58	4160.00	3074.00	2074.00	0.00	0.00
2006	2	51641.46	3780.00	2974.00	1974.00	0.00	0.00
2006	3	56827.18	15800.00	3684.00	2684.00	0.00	1520.00
2006	4	91223.02	51600.00	7428.00	6428.00	0.00	4560.00
2006	5	110000.00	78000.00	45188.94	44188.94	0.00	7220.00
2006	6	110000.00	96800.00	79757.70	78757.70	0.00	8360.00
2006	7	110000.00	21200.00	1995.59	995.59	0.00	8360.00
2006	8	110000.00	26500.00	12167.79	11167.79	0.00	5700.00
2006	9	110000.00	31400.00	23463.99	22463.99	0.00	1900.00
2006	10	109284.44	11900.00	6166.00	5166.00	0.00	380.00
2006	11	101323.27	1930.00	3442.00	2442.00	0.00	0.00
2006	12	95819.84	2310.00	3532.00	2532.00	0.00	0.00
2007	1	91823.03	4090.00	3104.00	2104.00	0.00	0.00
2007	2	93493.96	11200.00	4534.00	3534.00	0.00	0.00
2007	3	86799.82	2140.00	1354.00	354.00	0.00	1520.00
2007	4	81110.67	3210.00	1000.00	0.00	0.00	2488.00
2007	5	110000.00	59300.00	16447.57	15447.57	0.00	7220.00
2007	6	104003.31	7160.00	1000.00	0.00	0.00	3602.00
2007	7	97602.45	10060.00	1000.00	0.00	0.00	4910.00
2007	8	88227.50	4950.00	1000.00	0.00	0.00	5032.00
2007	9	79156.96	1380.00	2998.00	1998.00	0.00	1900.00
2007	10	71980.34	2320.00	3656.00	2656.00	0.00	380.00
2007	11	76647.65	17100.00	6472.00	5472.00	0.00	0.00
2007	12	84189.59	18300.00	6772.00	5772.00	0.00	0.00

Various variations of the tables included in Table 2.9 as well as a variety of other types of *SIM* simulation results can be created using *TABLES*. Program *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.

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. Program *TABLES* computes alternative variations of both period reliabilities based on percent-of-time and volume reliabilities based on percent of 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.

$$R_V = \frac{v}{V}\,(100\%) \qquad (2.2)$$

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:

$$R_P = \frac{n}{N}\,(100\%) \qquad (2.3)$$

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.

Diversion Shortage Metrics

Period and volume reliability, as defined in the preceding section and applied throughout the *Reference* and *Users Manual*, are fundamental metrics for evaluating water supply capabilities. Volume and period reliability tables are created with the *2REL* record routine in *TABLES*. Other auxiliary metrics presented in Chapter 5 are developed in a supplemental shortage table created by activating an option in field 7 of the *2REL* record. This auxiliary table includes the following metrics for summarizing shortages in supplying diversion targets for selected *WR* record water rights.

- maximum shortage during the simulation
- vulnerability defined as the average maximum shortage during each year of a long-term simulation or short-term sequence of a conditional reliability modeling (CRM) simulation
- resiliency defined as the inverse of the mean of the average length of shortage periods
- average severity defined as the average sum of consecutive shortages
- average number of failures per year or CRM sequence
- maximum number of consecutive shortages
- shortage index defined as

$$\text{Shortage Index} = \frac{100}{\text{months}} \sum \left(\left(\frac{\text{annual or sequence shortage}}{\text{annual or sequence target}} \right)^2 \right)$$

Frequency Analyses

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, instream flow shortages, reservoir storage, and surface elevation directly without a DATA record. A DATA record allows frequency analyses for all the variables in the *SIM* simulation results and other datasets created from the simulation results. Frequency tables may be for a specified month of the year such as August or for all months. A *2FRE* record frequency table may be in the row format illustrated in Table 2.9 or in an alternative column format that contains several more frequencies and is convenient to export to a Microsoft Excel spreadsheet.

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.

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

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. *2FRE* tables may be in a row format or in a column format containing additional frequencies. The *2FRQ* table also develops flow-frequency, storage-frequency, elevation-frequency, or instream flow shortage-frequency relationships. 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 1940-2007, covering a sequence of 816 months. The simulation begins with January 1940 naturalized stream flows and net evaporation rates and proceeds through the 816 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.*
- Short-term conditional reliability modeling simulations explained in Chapter 7 of this *Reference 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 8 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 IN THE SIMULATION MODEL

River system 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. This chapter discusses hydrology within the *SIM* simulation. *WRAP-HYD* described in the *Hydrology Manual* is designed to facilitate developing hydrology-related *SIM* input datasets. 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 present Chapter 3 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 or updating 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 in the *Hydrology Manual*, program *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*. *HYD* provides various hydrology data compilation capabilities, which among other capabilities include options for:

- converting observed gaged stream flows to naturalized stream flows
- distributing flows from gaged to ungaged locations using techniques that are also included in *SIM*
- adjusting stream flows to extend the hydrologic period-of-analysis or to develop condensed datasets
- updating the hydrologic-period-of- analysis by extending naturalized flows based on measured precipitation and evaporation rates

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 *SIM* reservoir volume accounting routines as described in the Chapter 4 section entitled *Iterative Reservoir Volume Balance Computations*.

Within the *SIM* simulation, 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.

- 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 the *SIM* simulation, 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.

Allocation of Stream Flow

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.

<u>Channel Losses</u>

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.

$$L = F_{CL}\, Q_{upstream} \tag{3.3}$$

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*.

<u>*Channel Losses in WRAP-SIM*</u>

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.

$$A_{adjusted} = A - D \tag{3.4}$$

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

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

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 *Nth* control point below the stream flow depletion is adjusted as follows, where F_{CL1}, F_{CL2}, F_{CL3}, ..., F_{CLN} denote the channel loss coefficients for each of the *N* individual reaches between the control point at which the stream flow depletion *D* occurs and the control point at which the amount of available water *A* is being adjusted.

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

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:

$$F_{adjusted} = F + A_F \tag{3.7}$$

The stream flow at the *Nth* control point below the diversion, reservoir, or other adjustment is adjusted as follows, where C_{L1}, C_{L2}, C_{L3}, ..., 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 $F_{adjusted}$ is being adjusted.

$$F_{adjusted} = F + [(1.0 - F_{CL1})\,(1.0 - F_{CL2})\,(1.0 - F_{CL3})\,...\,(1.0 - F_{CLN})]\,A_F \qquad (3.8)$$

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 and 10 involve distributing flows from a primary control point to a secondary control point. The same *INMETHOD(cp)* options 1-8 and 10 are also selected on the *HYD* control point *CP* record. Inflow options 1 and 2 and the flow distribution methods (options 3-8, 10) are the same in *HYD* and *SIM*. Option 9 is applicable only to *SIM*. *CP* record fields 11 and 13 in *SIM* allows the flows to be replaced by a specified constant flow.

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: $Q_{ungaged} = a\,(Q_{gaged})^b + c$
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. $Q_{ungaged} = Q_{gaged}\,R_{DA}$
8	An iterative algorithm incorporates channel losses in the NRCS CN method.
9	Flows are not provided for this control point.
10	Flows are computed in proportion to flows at other control points with Eq. 3.23.

The *CP* record field 6 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 in 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 6 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)

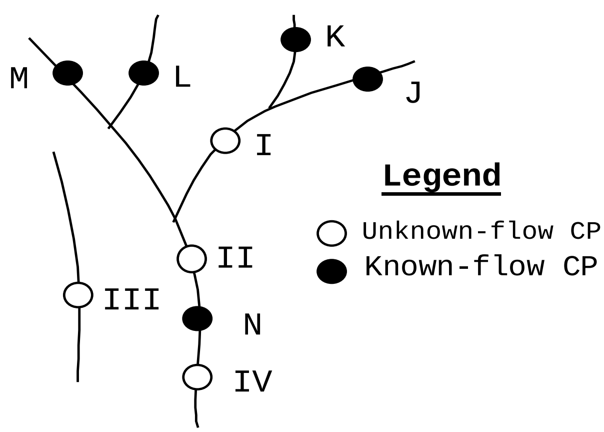

Figure 3.1 Gaged (Known-Flow) and Ungaged (Unknown-Flow) Control Points

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:

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

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. Option 10 is based on Equation 3.23 and is applied only to total flows. The flow distribution methods listed as options 3 through 8 in Table 3.2 may be applied to either total or incremental flows as defined by *FD* records and are based on either:

- the drainage area ratio R_{DA} $$Q_{ungaged} = Q_{gaged} R_{DA} \tag{3.9}$$

- the regression equation $$Q_{ungaged} = a\, Q_{gaged}^{\,b} + c \tag{3.10}$$

  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.

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

<u>*Multipliers and Control Point Identifiers on CP Records (Option 2)*</u>

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. 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.

<u>*Generalized Regression Equation (Option 3)*</u>

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.

$$Q_{ungaged} = a \, Q_{gage} \tag{3.12}$$

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

$$a = R_{DA} = \frac{A_{ungaged}}{A_{gage}} \tag{3.13}$$

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*.

$$a = \left(\frac{A_{ungaged}}{A_{gage}}\right)^{N1} \left(\frac{M_{ungaged}}{M_{gage}}\right)^{N2} \left(\frac{CN_{ungaged}}{CN_{gage}}\right)^{N3} \left(\frac{Other_{ungaged}}{Other_{gage}}\right)^{N4} \tag{3.14}$$

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

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

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) relationship is as follows.

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

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

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

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 ($M_{ungaged}/M_{gage}$) and substituted back into Equation 3.16 with the appropriate *CN* to determine *Q* for the ungaged 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_{gage} and multiplied by a unit conversion factor to convert to an equivalent depth Q_{gage} in inches.

Step 2: Q_{gage} is input to the curve number equation (Equation 3.16) to obtain P_{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 ungaged 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_{gage} by the ratio of the long-term mean precipitation depth of the subwatershed to that of the watershed to obtain a $P_{ungaged}$ adjusted in proportion to mean precipitation.

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

where $M_{ungaged}$ and M_{gaged} are the mean precipitation for the ungaged sub-watershed and gaged watershed. Otherwise, $P_{ungaged}$ is assumed equal to P_{gage}.

Step 4: $P_{ungaged}$ is input into Equation 3.16 to obtain $Q_{ungaged}$ in inches. $Q_{ungaged}$ in inches is multiplied by $A_{ungaged}$ 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.

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

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^3) 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 $MP_{ungaged}$ to MP_{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 a 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 situated is complicated by the fact that the flow at the ungaged site is a function of the flow at the gaged site Q_{gaged} plus channel losses $F_{CL}Q_{ungaged}$

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

and channel losses are a function of $Q_{ungaged}$ (loss = $F_{CL}Q_{ungaged}$). Thus, $Q_{ungaged}$ 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.

$$Q_{II} = f(Q_N+F_{CL}Q_{II})$$

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

$$Q_{II} = R_{DA} (Q_N + F_{CL}Q_{II})$$

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_{CL} determined by combining the channel losses F_{CLi} for each reach as follows:

$$\text{Equivalent } (1.0 - F_{CL}) = (1.0 - F_{CL1})\,(1.0 - F_{CL2})\,(1.0 - F_{CL3}) \,...\, (1.0 - F_{CLN}) \tag{3.19}$$

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_{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.

<u>Drainage Area Ratio with Channel Losses (Option 6)</u>

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

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

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.

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

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.

<u>NRCS CN Method with Channel Losses (Option 8)</u>

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

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

$$\text{Equivalent } (1.0 - F_{CL}) = (1.0 - F_{CL1})\,(1.0 - F_{CL2})\,(1.0 - F_{CL3})\ ...\ (1.0 - F_{CLN}) \tag{3.22}$$

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

1. For the initial iteration, the channel loss $F_{CL}Q_{ungaged}$ is set equal to zero, and thus ($Q_{gaged}+F_{CL}Q_{ungaged}$) is set equal to Q_{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 $Q_{ungaged}$ for the given ($Q_{gaged}+F_{CL}Q_{ungaged}$) from steps 1 and 3.

3. Given the $Q_{ungaged}$ computed in step 2 above, $F_{CL}Q_{ungaged}$ and thus ($Q_{gaged}+F_{CL}Q_{ungaged}$) 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 $Q_{ungaged}$ is less than 0.5 percent. The algorithm is terminated after 100 iterations and a warning message is recorded in the message file.

Flows as a Linear Function of Flows at Other Control Points (Option 10)

CP record *INMETHOD(cp)* option 10 determines flows at an ungaged site based on weighting flows at optionally one, two, three, or four control points using the following equation.

$$Q_{ungaged} = Q_0 + C_1Q_1 + C_2Q_2 + C_3Q_3 \tag{3.23}$$

Q_0, Q_1, Q_2, and Q_3 are the known total (not incremental) monthly naturalized flows at control points specified on the *FD* record. C_1, C_2, and C_3 are coefficients entered on a *FC* record.

The flows Q_0, Q_1, Q_2, and/or Q_3 at source (known-flow) control points are combined to compute the flow at the ungaged (unknown-flow) control point. From one to four source control points may be used. The option 10 control point identifiers are entered on the flow distribution *FD* record. Multiple source control points on the *FD* record for the other *INMETHOD(cp)* options define incremental watersheds and incremental flows, but the Q_0, Q_1, Q_2, and Q_3 flows in Equation 3.23 are total flows at the specified control points. Up to four source (known-flow) control points may be used but multiplier coefficients C_1, C_2, and C_3 can be assigned to flows at only three of the control points. The fourth coefficient C_0 for Q_0 is fixed at 1.0.

The flow coefficient *FC* record is used alternatively to enter the coefficients *a*, *b*, and *c* for Equation 3.10 or the coefficients C_1, C_2, and C_3 for Equation 3.23. Thus, the definition of the coefficients provided on *FC* records varies depending on whether *INMETHOD(cp)* option 3 or option 10 is specified on the *CP* record for a particular control point.

The coefficients C_1, C_2, and C_3 may be either positive or negative numbers. The coefficients may represent drainage area ratios or other parameters. If naturalized flows are known at all pertinent control points for a portion of the period-of-analysis or some period of time, the coefficients may be determined as ratios of mean flows. Choices of control points and positive and negative coefficients are based upon the ingenuity and judgment of the model-user and will vary with different river system control point configurations.

Control Point Ordering and Allowable Source Control Points

Primary control points are defined as locations at which flows are entered in a *SIM* input dataset as *IN* records in a flow file or DSS records in a DSS file. Secondary control points are sites for which flows are computed within the *SIM* or *HYD* programs based upon flows entered for one or more other control points, called source control points, using the methods listed in Table 3.2. Source control points are typically primary control points but can also be secondary control points under certain conditions outlined as follows.

Naturalized flows are established for each individual control point based on the *INMETHOD(cp)* portion selected on its *CP* record. The options are listed in Table 3.2. For a particular year and month of the *SIM* simulation or *HYD* application, naturalized flows are assigned to control points in the following sequential order.

Step 1.- Flows are read from *IN* records or DSS records for all primary control points in the sequential order in which the *CP* records are entered in the DAT file (option 1).

Step 2.- Flows may be transferred from primary control points to secondary control points based on the parameters *CPIN(cp)* and *CPDT(cp,1)* from the *CP* record (option 2). All secondary control points are considered in the sequential order of the *CP* records.

Step 3.- *INMETHOD(cp)* option 10 is activated as secondary control points are again considered in the sequential order in which the *CP* records are entered in the DAT file. Option 10 deals only with total flows, not incremental flows.

Step 4.- *INMETHOD(cp)* options 3 through 8 are activated as secondary control points are once again processed through a control point loop in the sequential order of the *CP* records. An incremental flow computational loop for all control points is followed by another loop that computes total flows. Options 3-8 preclude use as source control points.

The flows read from an input file for all primary control points as step 1 listed above may be used in computing flows at any of the secondary control points. Primary control points can always serve as source control points without any special considerations.

Option 2 secondary control points with flows assigned in step 2 can also serve as source control points for any of the other options 3, 4, 5, 6, 7, 8, and 10 secondary control points with flows assigned in the subsequent steps 3 and 4. Option 2 control points can also serve as sources for other option 2 control points as long as the *CP* record of the source control point is read from the DAT file earlier than the *CP* record of the control point to which flows are transferred.

The *INMETHOD(cp)* option 10 control points with flows assigned in step 3 can also serve as source control points for any of the options 3 through 8 control points with flows assigned in step 4. Option 10 control points can serve as flow transfer sources for other option 10 control points as long as the *CP* record of the source control point is entered in the DAT file ahead of the *CP* record of the control point for which flows are computed.

Control points with flows assigned in step 4 with *INMETHOD(cp)* options 3 through 8 should not be specified on *FD* records as serving as any type of source control points. Warning messages are written to the message file in most cases when source control points specified on a *FD* record are not valid based on the rules outlined above. However, these are warning messages rather than an error message, meaning that program execution is not terminated.

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.

Locations are defined based on control points. The *CP* record for each control point includes the identifier of the next downstream control point. The computational routines within WRAP use the designated next downstream control points to define spatial connectivity. Watershed drainage areas are required for all of the methods for distributing naturalized flows from gaged to ungaged sites. The curve number and mean precipitation are also required if the NRCS CN method adaptation is used for distributing flows. For river basins with numerous control points, GIS is very useful for developing these spatially oriented components of the input datasets.

<u>Negative Incremental Naturalized Stream Flows</u>

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 cumulative 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 other 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 inflows being negative.

<u>*ADJINC Options for Dealing with Negative Incremental Naturalized Stream Flows*</u>

Programs *HYD* and *SIM* include options, specified by variable *ADJINC* on the *JC* or *JD* record, to deal with negative incremental inflows. Options 1, 2, and 3 are incorporated in both *HYD* and *SIM*. The other *ADJINC* options listed below are relevant only to *SIM*.

Option 1: All downstream control points are considered in determining flow availability for each water right, and there are no negative incremental flow adjustments.

Option 2: Downstream negative incremental flow adjustments are applied at all control points at the beginning of the simulation.

Option 3: Upstream negative incremental flow adjustments are applied at all control points at the beginning of the simulation.

Option −3: Variation of option 3 in which incremental flow adjustments are applied only at primary control points, not control points with synthesized flows.

Option 4: As flow availability is determined for each water right at each time step during the simulation, upstream negative incremental flow adjustments are applied at the downstream control points but not at the control point of the right.

Option −4: Variation of option 4 in which incremental flow adjustments are applied only at primary control points, not control points with synthesized flows.

Option 5: The simulation algorithms are modified as discussed later for option 5. Whereas options 2, 3, and 4 involve computation of an array of flow adjustments, there are no negative incremental flow adjustments with option 5.

Option 6: Option 6 is same as option 4 except the downstream control points used in determining flow availability are limited to sites of senior rights. Simulation results are identical with either option 4 or 6 but execution time is reduced with option 6.

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

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

Negative incremental flow *ADJINC* options 1, 2, 3, −3, 4, −4, and 5 date back to early versions of WRAP. *ADJINC* options 6, 7, and 8 were added in early 2011. Option 4 has been the recommended standard. The new option 6 yields identically the same simulation results as option 4, but the computer runtime is reduced. Thus, option 6 replaces option 4 as the standard though reducing *SIM* execution time is not a major concern in most monthly simulation applications. Option 5 has also been applied extensively with the TCEQ WAM System. Option 7 is recommended whenever routing is adopted in *SIMD* daily simulations. Option 7 was created for *SIMD* daily simulations but can also be applied in *SIM* monthly simulations.

Options 1, 2, −3, 3, −4, and 8 are generally not good options for use in actual assessments of water availability. However, these *ADJINC* options provide opportunities for experimentation in simulation studies. Alternative simulations with these options provide insight on the effects of various premises on simulation results.

The remainder of this chapter is a discussion of the negative incremental flow options. Chapter 7 of TWRI TR-389 (Wurbs *et al*. 2011) is a case study comparative evaluation of the alternative *ADJINC* options.

NEGINC Options for Recording Information in the Message File

NEGINC options do not affect simulation results but rather print selected information in the message file which the user can examine to determine the extent of the negative incrementals. *NEGINC* options 1, 2, and 3 activated on the *SIM JD* record and *HYD JC* record date back to early versions of WRAP. Options 4 and 5 were added to *SIM* in early 2011.

Option 1 is the default of recording no negative incremental information in the message file.

Option 2 writes all negative incremental flows defined looking downstream for all months at all control points. The *downstream* negative incremental flow for a control point is the greatest negative difference between the naturalized flow at the control point and any other control point located downstream.

Option 3 writes all negative incremental flows defined looking upstream for all months at all control points. The upstream flow adjustments are defined as the minimum additional monthly volume that must be added at each control point to remove all negative incrementals in the set of all naturalized flows at all control points.

Option 4 provides just a summary table.

Option 5 lists all control points that have one or more negative incremental flows along with the number of negative incremental flows as well as the option 4 summary table.

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 of Table 3.3 and also discussed later, negative incremental flows may be eliminated by adjusting the flows at pertinent control points. Table 3.4 shows the amount of naturalized stream flow available for the most senior right for each of the *ADJINC* options.

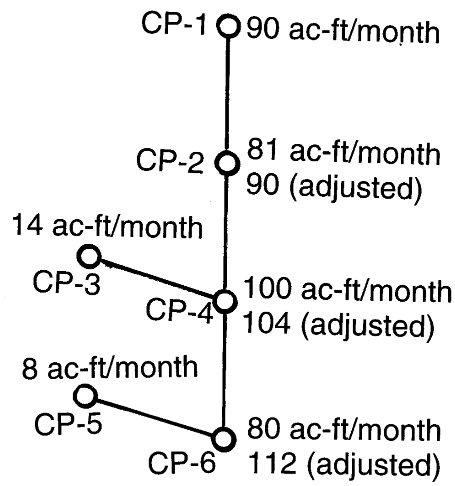

Figure 3.2 System with Negative Incremental Inflows

Table 3.3
Total and Incremental Naturalized Stream Flows for Example 3

1 Control Point	2 Naturalized Total Flow (ac-ft/month)	3 Adjacent CP Incremental Flow (ac-ft/month)	4 Downstream Negative Incremental (ac-ft/month)	5 Adjusted Total Flow (ac-ft/month)	6 Upstream Negative Incremental (ac-ft/month)	7 Adjusted Total 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 at the Beginning of the Simulation

1 Control Point	2 Naturalized Total Flow (ac-ft/month)	3 *CL(1)*=0.1 *CL(4)*=0.2 Avail Flow (ac-ft/month)	4 Option 1 Available Flow (ac-ft/month)	5 Option 2 Available Flow (ac-ft/month)	6 Option 3 Available Flow (ac-ft/month)	7 Options 4-8 Available 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 amount of naturalized stream flow available at the beginning of the simulation for the current month in Example 3 is shown in Table 3.4 for each of the *ADJINC* options. These amounts represent the stream flow available to the most senior right if it is located at each of the control points. The available flows for the month at the different control points at the beginning of the priority-sequenced water rights simulation are the same for *ADJINC* options 4, 5, 6, 7, and 8. However, stream flow availability may differ with these alternative *ADJINC* options activated as the simulation progresses through the water rights priority sequence.

The available flows for *ADJINC* option 1 with and without the optional *CP* record channel loss factors are tabulated in columns 3 and 4, respectively, of Table 3.4. The available flows in column 3 are based on combining the default (option 1) no incremental flow adjustments with channel loss computations 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 Table 3.3 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. Options 6 and 7 are the same as option 1 and 4, respectively, but consider only those downstream control points at which are located water rights that are senior to the current right.

Significance of Negative Incremental Naturalized Stream Flows

The *WRAP-SIM* simulation progresses through each monthly computational time step with each water right considered sequentially in priority order. Stream flow depletions and return flows associated with a water right affect stream flows at the control point of the water right and at control points located downstream. The simulation computations determine the amount of stream flow available to each water right in each month of the simulation as the lesser of the available stream flow at the control point of the water right and at downstream control points. Flows may be less at downstream control points due to two factors: (1) the effects of senior water rights in depleting flows and (2) negative incremental naturalized stream flows.

The relevance of flows being smaller downstream than upstream (negative incremental) is due to the effects on the amount of stream flow 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 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.

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.

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. 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 and peculiarities in *SIM* input datasets 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.

Channel Losses

Channel loss factors *CL(cp)* entered on the control point *CP* records in the *SIM* input DAT file are defined by Equation 3.3. *CL(cp)* are used in the various channel loss computations that occur throughout the *SIM* simulation. Conceptually, if the negative incremental flows are due strictly to channel losses, and if the linear channel loss equation (Eq. 3.3) 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. 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 and associated *SIM* channel loss computations.

In Example 3 (Figure 3.2), 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. The amount of water available at control point CP-4 for the first water right in the priority sequence is 100 acre-feet as shown in column 3 of Table 3.4. The 100 acre-feet of available stream flow at control point CP-4 is determined as the minimum of:

CP-4: 100

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

The 90 acre-feet at control point CP-1 is determined as the minimum of the following values.

CP-1: 90

CP-2: $90 = 81 / (1.0 - CL(1)) = 81 / (1.0 - 0.1)$

CP-4: $111 = 100 / [1.0(1.0 - CL(1))] = 100 / [1.0(1.0 - 0.1)]$

CP-6: $111 = 80/[(1.0 - CL(4))(1.0)(1.0 - CL(1))] = 80/[(1.0-0.2)(1.0)(1.0-0.1)]$

<u>*Downstream versus Upstream Negative Incremental Flow Adjustments*</u>

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.

ADJINC option 2 is based on downstream negative incremental flow adjustments as defined above. *ADJINC* options 3, 4, and 6 are based on upstream negative incremental flow adjustments. The other *ADJINC* options do not develop negative incremental flow adjustments.

Description of ADJINC Options for Dealing with Negative Incrementals

Option 1 consists of considering all downstream control points and applying no flow adjustments in determining the amount of stream flow available to each water right. Water rights are subject to being penalized for negative incremental naturalized flows at any downstream control points regardless of whether senior water rights are located there. Option 1 places maximum restrictions on the amount of stream flow available to the water rights. Use of the channel loss option reduces or eliminates 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, option 1 may be reasonably accurate.

Options 2 and 3 replicate older practices predating WRAP in which naturalized flows are adjusted to remove negative incrementals prior to inputting them to a simulation model. Modelers have in the past adjusted naturalized flows to remove negative incrementals in the process of compiling input datasets for *WRAP-SIM* or other models. Options 2 and 3 perform the flow adjustment computations at the beginning of the *SIM* execution in conceptually the same manner as traditional methods for adjusting the naturalized flows outside of the model.

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. 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 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 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.

Options −3 and −4 are variations of options 3 and 4 in which incremental flows are defined in terms of only those control points for which *INMETHOD* in *CP* record field 6 is 0, 1, or 2. This includes the control points for which inflows *IN* records are entered in the *SIM* input data and those for which flows are transferred using *INMETHOD* 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.

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.

CP-2: 81
CP-4: 104 = 100 + 4
CP-6: 112 = 80 + 32

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 is 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.

Channel loss computations activated by non-zero loss factors on *CP* records are 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.

CP-1: 90

CP-2: 90 = maximum of: 81 / [1.0(1.0 − *CL(1)*)] = 81 / 0.9 = 90
81 + 9 = 90

CP-4: 111 = maximum of: 100 / [1.0(1.0 − *CL(1)*)] = 100 / 0.9 = 111
100 + 4 = 104

CP-6: 112 = maximum of: 80 / [(1.0 − *CL(4)*)(1.0)(1.0 − *CL(1)*)] = 80/[(0.8)(0.9)] = 111
80 + 32 = 112

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

CP-2: 81

CP-4: 111 = maximum of: $100 / [1.0(1.0 - \mathit{CL(1)})] = 100 / 0.9 = 111$
$100 + 4 = 104$

CP-6: 112 = maximum of: $80 / [(1.0 - \mathit{CL(4)})(1.0)(1.0 - \mathit{CL(1)})] = 80/[(0.8)(0.9)] = 111$
$80 + 32 = 112$

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

CP-4: 100

CP-6: 112 = maximum of: $80 / (1.0 - 0.2) = 100$
$80 + 32 = 112$

Simulation steps. Regardless of negative incremental option, in each month, as each water right is considered in turn in priority order, the *SIM* simulation proceeds through three steps:

1. The amount of stream flow available to that water right is determined as the minimum of available stream flows at the control point of the right and downstream control points.
2. Water accounting computations are performed to determine the stream flow depletion, return flow, reservoir storage contents, and other quantities for the water right.
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 the first and third steps listed above. With option 5, incremental flows are not computed, and there is no negative flow adjustment array developed prior to the simulation like options 2, 3, and 4. Option 5 is incorporated in steps 1 and 3 listed above as follows.

- In the above step 1 determination of the amount of stream flow available to a water right, with option 5, the only downstream control points considered are those at which senior rights are located. Furthermore, no control points with zero flow or located downstream of a discontinuity of flow (control point with zero flow) are considered regardless of senior rights.
- In the third step listed above, option 5 limits the flow adjustment to not exceed the minimum of the regulated flows at any of the intermediate control points between the current upstream water right being simulated and downstream senior rights. The adjustments stop if a control point with zero regulated flow is encountered. Option 5 is the only *ADJINC* option that includes modification of the step 3 computations.

Option 6 is a modified version of option 4 designed to reduce computer execution time. Regardless of *ADJINC* option, the amount of stream flow available to a water right is determined as the minimum of available flows at the control point of the right and relevant downstream control points. Option 4 considers all downstream control points in searching for the constraining site without identifying which of the downstream control points represent locations of water rights that are senior to the current water right being simulated. Option 6 identifies the control points at which relevant senior rights are located and limits consideration to only those control points. Relevant downstream senior rights are those that appropriate stream flow which excludes types 3, 4, and 6 specified by *WR* record field 6 and defined in Chapter 4. Option 6 also stops the cascading search for the minimum flow whenever a control point with zero flow is found.

Option 6 allows *SIM* to run a little faster than option 4. With negative incremental flow adjustments applied, senior rights are the only downstream constraint on the flow available to upstream water rights. Thus, options 6 and 4 always yield the same simulation results.

Option 7 is designed to be the standard *ADJINC* option to be adopted in *SIMD* whenever routing and forecasting are employed, but can also be used in a monthly or daily simulation without routing and forecasting. As explained in the *Daily Manual*, in applying option 7 with *SIMD* routing and forecasting, the downstream control points identified in the *SIMD* reverse routing are further constrained to only those control points at which relevant senior rights are located. Relevant downstream senior rights are those that appropriate stream flow which include instream flow *IF* record rights and *WR* record types 1, 2, 5, and 7 as defined in Chapter 4.

Flows at downstream control points with no senior rights have no effect on water availability for the junior right with option 7. Therefore, negative incremental flows at a downstream control point affect the amount of flow available to a particular water right only if senior rights also reduce the flows at the downstream control point. Option 7 is similar to option 5 but does not include all of the features of option 5. Option 7 is option 1 with the limitation to senior right control points added. Relevant senior rights are the same with options 6 and 7.

Option 8 ignores downstream control points in the determination of the amount of stream flow available to a water right. Thus, junior water rights can erroneously appropriate stream flow that has already been appropriated by downstream senior rights. This *double-taking* of the same water introduces errors in the simulation. Option 8 is valid only if all water right priorities correspond to upstream-to-downstream order. Thus, option 8 should normally not be adopted except for experimentation. Option 8 is designed for experimentation. The effects on junior rights resulting from not passing inflows to protect downstream senior rights can be explored.

Examples Comparing Options 1, 4, 5, 6, and 7

The following simple examples are used to compare *ADJINC* options 1, 4&6, 5, and 7. Options 4 and 6 are the same. Referring to Example A, with either option 1, 4, 5, 6, or 7:

- 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.

In Example A, 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 options 4 and 6, water availability at CP1 is not limited by negative incremental flow occurring downstream. With options 5 and 7, water availability at CP1 is limited by the flow at CP3 only if there is a senior right at CP3.

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	Options 4,6	Options 5,7
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	Options 4 and 6	Options 5 or 7
40/0.5=80	Min[100 and maximum of (40+70=110 and 40/0.5=80)] = 100	100 at CP1
10/0.5=20	Min[100 and maximum of (10+70=80 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	1	4,6	5	7
WR1 at CP1 is senior to WR of any amount at CP3	0	100	100	100
WR1 at CP1 is junior to WR of any amount at CP3	0	100	100	0

computed as follows

Option 1	Options 4 and 6	Options 5 or 7
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	Options 4,6	Options 5,7
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	Options 4 and 6	Options 5 or 7
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	Options 4,6	Options 5,7
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	Options 4 and 6	Options 5 or 7
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

With option 1, stream flow availability may be limited by negative incremental flows at any downstream control point with or without senior rights. With options 4 and 6, flow availability is never limited by negative incremental flows at downstream control points regardless of senior rights. With options 5 and 7, stream flow availability may or may not be limited by flows at downstream control points depending on senior rights.

Considerations in Comparing ADJINC Options

The combination of actual factors causing 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 included in the *SIM* input dataset and associated computational routines
2. temporary channel losses, again over and above those captured by the *SIM* channel loss computations, where bank storage or underflow may reenter the stream at a downstream location and/or during a future time period
3. timing effects of runoff from a rainfall event reaching an upstream control point in a particular month but reaching a downstream control point early in the next month
4. inaccuracies and lack of precision in stream flow measurements at gages and in computations to convert gaged flows to naturalized flows
5. peculiarities in *SIM* input datasets in establishing control points and assigning naturalized flows to the control points

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 *ADJINC* options (except option 8) if there are no negative incremental flows.

Senior rights are protected from junior rights regardless of which *ADJINC* option is selected to deal with negative incremental flows. In all cases, stream flows are allowed to *"pass through"* to accommodate senior water rights located downstream. The *ADJINC* options differ in regard to whether junior right appropriations are also curtailed to *"pass through"* flows to mitigate negative incremental flows occurring downstream even though the flows available to senior rights are not increased in the model by this curtailment. In comparing *ADJINC* options, the following key question is considered from the perspective of properly modeling the impacts of senior rights on junior rights, not vice versa. In order to not reduce flows 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 occurring in river reaches in between, in addition to maintaining flows available to the senior rights?

Summary Comparison of ADJINC Options

Option 4 has been the standard *ADJINC* option recommended in the *Reference Manual* for most applications since the initial versions of WRAP. Option 6 was added in 2011 for the sole purpose of reducing computer execution time while replicating option 4 simulation results. Options 6 and 4 yield the same simulation results though option 6 runs a little faster. Option 6 is now the default standard option for a monthly simulation or sub-monthly (daily) simulation without routing. Option 7 is the recommended standard for a sub-monthly (daily) simulation with routing and forecasting. The 2011 addition of option 7 was motivated by the daily *SIMD* but is also applicable for monthly *SIM* simulations. Option 5 provides an alternative viable methodology which has also been routinely applied with the TCEQ WAM System datasets.

With options 4 and 6, stream flow availability for a water right is not affected by negative incremental flows occurring downstream. With options 1, 2, 5, and 7, the amount of water available to a right may be reduced by negative incremental flows occurring at downstream control points. With options 5 and 7, the amount of water available to a right is reduced by negative incremental flows occurring only at those downstream control points at which are located water rights that are senior to the water right currently being simulated.

The following premises are reflected in the alternative *ADJINC* options in determining the amount of stream available to each water right. The term *excess negative incremental flow* is adopted here to refer to the portion of a negative incremental flow not accounted for by the *SIM* channel loss computations that use the channel loss factors provided as input on *CP* records.

- Option 1 is based on the premise that flow at upstream locations must be committed to mitigating excess negative incremental flows at all downstream control points to prevent negative regulated flows either with or without the existence of downstream senior rights.

- Option 5 is based on the premise that upstream flows must mitigate downstream excess negative incremental flows prior to meeting 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 (zero flow) between the control point of the downstream senior right and the upstream control point for which water availability is being determined. The premise is that junior rights located upstream must curtail stream flow depletions as necessary to mitigate excess negative incremental flows (viewed primarily as channel losses) even though the curtailment does not increase the flow available to downstream senior rights.

- Option 7 is likewise based on the premise that upstream flow must be used to mitigate excess negative incremental flows prior to meeting downstream water right requirements. Incremental flows are considered only at downstream control points at which relevant senior rights are located. Senior rights are relevant only if they are *WR* record field 6 type 1, 2, 5, or 7 rights (defined in Chapter 4) which appropriate stream flow or instream flow *IF* record rights. In a *SIMD* daily simulation, only control points identified in the reverse routing algorithm described by the *Daily Manual* are considered.

- Options 4 and 6 are based on the premise that excess negative incremental flows at downstream control points do not affect water availability for water rights located at an upstream control point. Stream flows are passed to meet senior water right requirements at downstream control points, adjusted for channel losses computed based on the channel loss factors entered on the *CP* records. However, water availability at an upstream control point is not reduced for negative incremental flows assigned to downstream control points.

Another difference between option 5 and the other *ADJINC* options relates to flow adjustments for the effects of stream flow depletions. In cascading downstream flow reductions resulting from stream flow depletions made by water rights, option 5 limits the flow adjustment to not exceed the minimum regulated flow at intermediate control points. The other *ADJINC* options include no modifications to the algorithms that cascade the effects of water rights on downstream flows. With options other than option 5, the flow at a downstream control point can be reduced more than the regulated flow of another intermediate control point located upstream.

CHAPTER 4
WATER MANAGEMENT

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 requirements, 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*, *LO*, *FS*, *CV*, *TS*, and *PX* records are connected to a *WR* or *IF* record 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 *Daily Manual* are defined as *FR*/*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 necessarily 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
- specified limits or rules for computing limits on stream flow depletions
- annual limits on total diversions or diversions from storage
- identifiers for labeling rights and aggregating simulation results for groups of related rights

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. *SIM* also has alternative options other than the priorities on *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 *NPOPT* 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 *NPOPT* 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 *NPOPT* 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
<u>Priority-Based Water Rights Computation Loop</u>

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 from 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.

Water Right Types

All *WR* record water rights are categorized as being either type 1, 2, 3, 4, 5, 6, 7, or 8 by the entry in field 6 of the *WR* record. This categorization by type is not applicable to instream flow *IF* record water rights. 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 described as follows.

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

Type 8: target is computed solely for use by other water rights that reference the target

Table 4.1
Features of Each Water Right Type

	Water Right Type (*WR* Record Field 6)							
River/Reservoir System Operation	1	2	3	4	5	6	7	8
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) cannot 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 cannot 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.

Type 8 right.- A type 8 right only creates a target volume and/or flow switch with no other computations performed for that water right. Targets can be developed using *UC*, *TO*, *TS*, *SO*, *DI/IS/IP*, *BU*, *CV*, and *FS* records along with the *WR* record target setting features. However, the target for a type 8 water right is not used by that right, and the right is not further simulated. The only reason for a type 8 water right is to allow its target to be used by one or more other *WR* or *IF* record water rights in assigning or adjusting their instream flow, diversion, hydropower, or storage targets, reservoir release limits, or stream flow depletion limits. A type 8 right, like any other right, can be referenced by *TO*, *LO*, *FS*, and *CV* records. *WR*, *IF*, and *OR* records can connect to *FS* or *CV* records contained with the record set of another water right.

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 cannot 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. Any number of 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. Reservoir operations are defined by water right type specified on *WR* records and rules specified on operating rules *OR* records along with parameters on *WS*, *HP*, and other records.

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.

SIMD allows gated or ungated flood control or surcharge storage capacity above the top of conservation pool to be included in the simulation, as described in the *Daily Manual*. However, *SIM* has no features for modeling flood control operations. In *SIM*, when a reservoir is full to the storage capacity defined by *WS* record field 3, outflow equals inflow.

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:

$$A = aS^b + c \tag{4.1}$$

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 keep 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 6 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.

Operating rules may range from very simple to very complex. 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
- water right features associated with *WR* and *IF* records and auxiliary *SO*, *ML*, *TO*, *LO*, *FS*, *CV*, *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 and target setting options including storage targets
- drought indices allowing diversion, instream flow, hydropower, and storage targets to be specified as a function of storage content (*DI/IS/IP/IM* records)
- monthly varying limits on storage capacity (*MS* record)
- reservoir release capacity (*OR* record) which may be varied with flow conditions (*FS* and *CV* records which connect to target setting records)
- multiple reservoir system operating rules (*OR* record)
- multiple owners sharing storage in the same reservoir (*EA* record)
- hydroelectric power features of a project (*HP* record)
- priority sequence circumvention options (*PX* records)

Most aspects of modeling water rights covered throughout this chapter are relevant to reservoir system operations. Later sections of this chapter focus specifically on (1) multiple rights associated with the same reservoir and (2) multiple reservoirs associated with a single right. *SIMD* flood control operations are covered in the *Daily Manual*.

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.

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 discussed later in this chapter, 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 of stream flow, storage, and specified upper and lower limits by options controlled with supplemental options *SO*, target options *TO*, cumulative volume *CV*, and flow switch *FS* 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.

A diversion shortage is declared any time the diversion target cannot 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.

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. 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 *SIM* 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 return flow factor and 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* in *WR* record field 7 specifies the return flow method adopted for the water right as follows.

0 Default *RFD* from *JO* record field 11 is adopted. Option 1 is the *RFD* default.

1 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 between years. The adjustments from the *FA* or *CI* records are applied by the *SIM* model in essentially the same manner. 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 most common applications of *CI* records are to model (1) return flows not otherwise included in the return flow options, such as return flows from water supply withdrawals from groundwater aquifers and (2) interbasin transfers of water to the control point. *FA* records have been used to enter flow adjustments representing interactions between groundwater and stream flow associated with aquifer pumping. In general, *CI* or *FA* records could also be used to model diversions not otherwise included in the water rights, channel losses not otherwise modeled in the channel loss computations, or other flow features.

The following discussion focuses on *CI* record adjustments but is also pertinent to *FA* record adjustments which are described in the *Users Manual*. 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. 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 tail-water elevation (*HP* record) or tail-water 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 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 cannot be added.

Energy generation target and shortage amounts are written to reservoir/hydropower project and/or water right output records in the *SIM* output OUT file and tabulated with *TABLES*. Energy generation target and shortage amounts associated with individual hydropower rights are also stored in a HRR file and reorganized as tables with *TABLES*. 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]
- tail-water elevation [*HP* record field 3] or tail-water 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:

$$E = P\,t \tag{4.2}$$

$$P = \gamma\,Q\,H\,e\ (\text{unit conversion factors}) \tag{4.3}$$

$$E = \gamma\,Q\,H\,e\,t\ (\text{unit conversion factors}) = Q\,H\,e\,t\,(POWFCT) \tag{4.4}$$

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]

γ − unit weight of water [lb/ft^3, kN/m^3]

Q − discharge through turbines during time period [ac-ft/month; 10^3 m^3/month]

H − head [feet, meters]
= mean reservoir water surface elevation for period minus tail-water 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:

$$E = Q\,H\,e\,t\,(POWFCT) \tag{4.5}$$

where:

$$POWFCT = \gamma \text{ (unit conversion factors)} \tag{4.6}$$

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 4.2 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 4.2. Thus, the default *POWFCT* = 0.0010237 automatically used by *SIM* is appropriate if the variables are expressed in the following units:

POWFCT = 0.0010237
energy (E) in megawatt-hours (MW-hrs)
discharge (Q) in acre-feet/month
head (H) in feet

If other units are adopted, a value for *POWFCT* must be entered in field 7 of the multiplier factor *XL* record.

Table 4.2
Hydropower Factor for Alternative Sets of Units

specific weight γ	9.80 kN/m^3	9.80 kN/m^3	9.80 kN/m^3	62.4 lb/ft^3	62.4 lb/ft^3	62.4 lb/ft^3
units for:						
volume/period, Q	m^3	1,000 m^3	10^6 m^3	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
POWFCT	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.

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

$$\left(62.4 \ \frac{\text{lbs}}{\text{ft}^3}\right)\left(\frac{\text{ac-ft}}{\text{month}}\right)(\text{feet})(\text{month})\left(\frac{43{,}560\,\text{ft}^3}{\text{acre}\bullet\text{feet}}\right)\left(\frac{\text{m}}{3.281\,\text{ft}}\right)\left(\frac{\text{N}}{0.2248\,\text{lbs}}\right)\left(\frac{\text{hour}}{3{,}600\,\text{s}}\right)\left(\frac{\text{MW}}{1{,}000{,}000\,\text{W}}\right)$$

$$E = Q \, H \, e \, t \, (0.0010237)$$

As noted in Table 4.2, the value for *POWFCT* is 2.7222 if the following units are adopted: flow volume for period t in 1,000 cubic meters (10^3 m^3), 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.

<u>*System Operating Rules for Hydroelectric Power*</u>

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 tail-water 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 cannot 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 later 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/IM*, target options *TO*, supplemental options *SO*, flow switch *FS*, cumulative volume *CV*, and/or target series *TS* 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 or optionally the largest or smallest controlling at different priorities.

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 6 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. 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/IM* 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/IM*, *TO*, *SO*, *FS*, *CV*, *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 8. *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 affect 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 7 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.

Same IF Record Right Applied at All Control Points in a Stream Reach

The instream flow target defined by the *IF* record and its auxiliary records is repeated at all control points between the control points entered in *IF* record fields 2 and 12. If the optional *IF* record field 12 is blank, the instream flow requirement is applied only at the control point entered in the required field 2. The optional parameter CP2 in *IF* record field 12 defines a stream reach extending from the control point specified in *IF* record field 2 downstream to CP2. This reach may contain any number of control points. CP2 in *IF* record field 12 is the identifier of a control point located further downstream, with the exception that OUT entered in field 12 assigns CP2 as the outlet. The instream flow target is set at all control points in the reach.

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. *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 8 *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 procedures outlined later in this chapter based on information entered on *IF*, *UC*, *DI/IS/IP/IM*, *TO*, *FS*, *CV*, *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 units, is the difference between the instream flow target and the regulated flow. 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.

<u>*Second Pass through Water Rights Loop (Options –2 and –4)*</u> *IF* record field 8 *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.

<u>*Single Pass through Water Rights Loop (Options 1 and 3)*</u> 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.

<u>*Reservoir Storage for Meeting Instream flow Requirements (Options 3 and 4)*</u> 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 (*IFMETH* 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.

<u>*Regulated Flows and Instream Flow Targets*</u>

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 or *FA* 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.

The single-pass *IFMETH* options 1 and 4 are the recommended default standard. The more complicated two-pass *IFMETH* options 2 and 4 should be applied with caution and only if specific reasons warranting switching to the two-pass strategy are clearly identified.

<u>Specifying Targets and Rules for Meeting the Targets</u>

WRAP-SIM provides considerable flexibility for modeling complex water resources, development, allocation, management, and use practices. 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 4.3 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. Reservoir storage parameters on *WS* records and operating rules on *OR* records may be associated with either *WR* or *IF* records.

Table 4.3
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*, *CV* records)
* drought index that allows diversion, instream flow, and hydropower requirements to vary as a function of reservoir storage (*DI*, *IS*, *IP*, *IM* records; *IF* field 10; *WR* field 11)

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)
* limits on stream flow depletions (*SO* fields 3-4 and 11-12; *ML* record; *LO* 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, 7, or 8 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

Type 8: target is computed solely for use with other water rights

---

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.

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.

In addition to the features listed in Table 4.3, 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 multiple-owner and multiple-reservoir operating rules for meeting the targets (Tasks 2 & 3) are then described. The chapter then covers the dual simulation option and options for modeling water management schemes that circumvent the priority sequence. Other special optional modeling capabilities are also presented in the remainder of the chapter.

<u>Setting Diversion, Instream Flow, and Hydropower Targets</u>

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, and other variables, 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 referencing a set of 12 monthly distribution factors entered on *UC* records. However, ingenuity may be applied to combine any number of the options outlined below to model complex and/or unique water management situations.

The sequentially ordered steps described below are governed by *WR/IF/UC*, *BU*, *DI/IS/IP/IM*, *TO*, *TS*, *CV*, *FS*, and *SO* records. Embedded within the sequence of tasks, optional step 4 consists of a series of any number of target building tasks with each task being governed by a separate *TO* record. Steps 2 and 10 apply a *BU* record backup feature based on shortages from one or more other *WR* record rights. Step 9 consists of referencing a *FS* or *CV* record located in the record group of another water right with its own *WR/IF/UC*, *BU*, *DI/IS/IP/IM*, *TO*, *TS*, *CV*, *FS*, and *SO* records. These cross-connections between water rights provide considerable flexibility in setting targets but also add complexity in describing and applying modeling options.

In a given month of the simulation, as the water rights are considered in turn in priority order, *SIM* builds a monthly diversion, instream flow, or hydroelectric energy target for the current water right in sequential steps as outlined below.

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 10. Optional step 2 consists of adding the shortages incurred by one or more other *WR* record water rights to the target of the current right determined in step 1 above.

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. Step 3 consists of multiplying the target volume determined in steps 1 and 2 above by a factor determined by the drought index as a function of reservoir storage.

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 intermediate target determined in the preceding steps outlined above. Each subsequent *TO* record results in another target to be combined with the preceding intermediate target. The two 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 one or more specified reservoirs. The preceding intermediate target is multiplied by a factor determined from a relationship defined by *DI/IS/IP* records. The drought index may be applied at either step 3 or step 6.

7. The target is constrained by upper and lower limits entered in *TO* record fields 5 and 6 if TOTARGET option 10 is specified in *TO* record field 2. Otherwise, these *TO* record limits are included in step 4.

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

9. The *FS* or *CV* record for step 9 is entered with another water right and referenced by an integer identifier in *WR* field 10 or *IF* field 9 of the current right. A negative *FS* record reference results in the target of the current right being multiplied by a flow switch consisting of a factor selected by the referenced *FS* record. Otherwise, the referenced *FS* or *CV* record provides a target volume for the current right. The target volume or switch multiplier factor provided for the current right by the *FS* or *CV* record may reflect the

preceding steps 1-8 for the water right record group in which the *FS* or *CV* record is located. Water right type 8 allows a right to be used solely for this type of *FS/CV* record application.

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

11. The target is adjusted as necessary to prevent exceeding the optional monthly or annual reservoir withdrawal limits entered in *SO* record fields 7 and 8.

12. The target is adjusted for the annual or seasonal diversion or regulated flow limits of *SO* record field 10.

SIM applies steps 1 through 10 are in sequential order to set the diversion, instream flow, or hydropower target for a water right. Steps 11 and 12 refer to additional adjustments to the target governed by *SO* record parameters that limit the amount of water available to the 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.

Intermediate targets may be computed in the 12-step process outlined above of setting the actual target to be used in the simulation. Only one of these targets and associated shortage are written to the *SIM* output file. *ISHT(wr)* in *SO* record field 9 specifies which target and corresponding shortage to write to the output file. The default (blank field 9) is to write the final target and shortage at the end of the computations to the output file. Entering a 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 in *SO* record field 9 results in recording the monthly target at the completion of the specified step. If the steps 2 through 12 options are not applied, the same step 1 target and shortage are written to the output file regardless of the *ISHT(wr)* entry.

The final target is always used in the simulation computations. *ISHT(wr)* in *SO* field 9 governs the choice of which monthly targets and shortages are written to the *SIM* output file. The simulation computations are not affected in any way except for the back-up feature activated by a *BU* record or *SO* record field 6. The shortage of the other rights added to the target of the back-up right is the shortage specified by *ISHT(wr)*.

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

The target options *TO* record provides options implemented as step 4 of the sequential 12-step process described in the preceding section for computing monthly diversion or instream flow targets as functions of (a) naturalized, regulated, or unappropriated 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.

The following simple example illustrates the general approach of applying *TO* records. Example 7 in Appendix B provides further illustration.

<u>*Example:*</u> 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.

```
**
**                          Record Fields
**|  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.

Flexibility is provided by *TO* record options to creatively combine target-building features in a variety of ways to model a broad range of water management situations. Targets can be computed by *SIM* by adding and/or subtracting 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.

Diversion, Hydropower, and Instream Flow Target 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 the results of previous *SIM* simulations. The *TS* record targets may be the only requirements specified for a particular water right or alternatively may be integrated with other target-building options. Targets from *TS* records are integrated into the sequential step-by-step *SIM* target building scheme as step 5 of the previously outlined 12-step process. *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. Examples 7 and 18 in Appendices B and C include *TS* records.

Drought or Storage Index

The various options activated by the *WR*, *IF*, *SO*, *TO*, *FS*, *CV*, *TS*, and *DI/IP/IS/IM* records may be combined in a myriad of ways to define diversion, instream flow, and hydropower targets. Drought indices defined by sets of *DI*, *IP*, *IS*, and *IM* records may be combined with the other records in the target building process or alternatively may be applied independently. Examples 4 and 11 in Appendix B illustrate the use of *DI*, *IP*, *IS*, and *IM* records.

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 on an *IF* or *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.

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.

An *IM* record consists of switch variable entries for each of the 12 months of the year. A *DI/IS/IP* record index can be applied with or without adding an *IM* record. An *IM* record allows the *DI/IS/IP* storage index to be switched on or off in each month, meaning the *DI/IS/IP* record storage index is applied only in specified months of the year. Alternatively, using the *IM* record, the index determined based on reservoir storage contents in a selected month may be repeated in later months. For example, the index applied in setting a target during each month of October through February could be determined based on the storage content at the beginning of October.

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.

The switching-variable *EMPTY* of the *DI* record allows reservoirs to 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. This *DI* record emptying feature was added to *SIM* prior to the addition of the

FS and *CV* record features described in the next section and is now essentially superseded by the newer *FS* and *CV* records. The *EMPTY* feature is designed to be used to specify targets as a function of cumulative flows or diversions. For example, 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.

Example Drought Indices

The following two drought indices are incorporated in Example 7.5 in Chapter 7 of the *Daily Manual*. Instream flow targets records are developed by *IF* records connected to the *DI* records.

```
DI     1       3  Belton  George   Grang
IS     4     0.0 224080. 224080. 1466320
IP           0.0     0.0   100.0   100.0
IM     1   2   3   4   5  -5  -5  -5  -5  -5  11  12
**
DI     2       3      PK    Whit   WacoL
IS     4     0.0 555776. 555776. 3391940
IP           0.0     0.0   100.0   100.0
```

Drought conditions for water rights connected to the two drought indices are defined as the storage contents of the reservoirs falling below 40 percent of their conservation storage capacity. Drought index 1 is based on the total storage contents of three reservoirs with identifiers Belton, George, and Grang and a total storage capacity of 1,466,320 acre-feet including conservation and flood control pools. The 224,080 acre-feet on the *DI* record represents 40 percent of their total conservation storage capacity. The drought index is 0.0%, representing a target multiplier factor of 0.0, if the total storage in the three reservoirs is at or below 224,080 acre-feet and 100%, representing a target multiplier factor of 1.0, is the storage exceeds 224,080 acre-feet. Likewise, drought index 2 is defined similarly by the second set of *DI*, *IS*, and *IP* records similarly based on three other reservoirs (PK, Whit, and WacoL) located in a different sub-basin.

Drought index 1 is set at the beginning of January, February, March, April, May, November, and December and applied that month. The drought index set at the beginning of May is applied in May, June, July, August, September, and October. For drought index 2, the index is reset each month based on beginning-of-month storage that month and applied in setting targets that month.

***FS* and *CV* Record Options Based on Cumulative Volumes**

Flow switch *FS* and cumulative volume *CV* record options use a cumulative volume of a selected variable in developing

- *IF* record instream flow targets,
- *WR* record diversion, hydropower, or storage targets,
- *LO* record maximum stream flow depletion limits, or
- *OR* record maximum reservoir release limits.

A multiple-period past history of flows or other quantities is incorporated in setting instream flow, diversion, and hydropower targets. *FS* and *CV* records can also be used with type 7 rights (*WR* field 6) and reservoir release capacities (*OR* fields 9, 10, 11) in defining reservoir operating rules or with *LO* records for setting maximum limits on stream flow depletions. Any number of *FS* and *CV* records can be provided for any of the water rights in a *SIM* input dataset. Any number of water rights can apply the same *FS* or *CV* record. Examples 10, 11A, and 11B in Appendix B of this manual focus on *FS* records. Example 7.5 in Chapter 7 of the *Daily Manual* illustrates the use of *FS* and *CV* records to set daily instream flow targets.

One of the following *FSV* or *CVV* variables is selected in *FS* or *CV* record field 3.

1. regulated flow at a control point either including or excluding reservoir releases
2. naturalized flow at a specified control point
3. unappropriated or available flow at a specified control point
4. stream flow depletion at a specified control point
5. diversion at a specified control point
6. inflow to a control point excluding upstream releases
7. stream flow depletion for a specified water right
8. total diversion for a specified water right
9. diversion from reservoir storage for a specified water right
10. target for a specified water right
11. instream flow shortage for an *IF* record right
12. hydrologic index series provided on *HI* records in a HIS file

The cumulative volume of the selected variable is computed by *SIM* by summing over the current and/or specified number of preceding time intervals. The preceding time period over which the selected variable is accumulated (summed) is defined by specifying the number of intervals and relevant season of the year. The *FS* and *CV* records include parameters for specifying a length of time that may include the current month and any number of preceding months in the *SIM* simulation (or days in *SIMD*). The time period may be limited to a season of the year defined by beginning and ending months of the relevant season of an annual cycle.

The choices of flow switch *FSV* or cumulative volume *CVV* variable and the rules for defining the time period over which the volume for this variable is summed are identically the same with either the *FS* or *CV* record. However, the options for using the cumulative volume to develop water right targets, stream flow depletion limits, or reservoir release limits differs between the *FS* and *CV* records. *FS* and *CV* record capabilities are described as follows.

FS Record Flow Switch

The primary motivation for including the flow switch feature in WRAP is flexibility in modeling environmental instream flow requirements. However, the *FS* record options may be also applied in setting water supply diversion target, hydropower generation targets, reservoir storage targets, maximum stream flow depletion limits, and reservoir release capacities.

The computational time step is a month in *SIM* and typically a day in *SIMD*. In many applications, the *FS* record modeling feature will be more realistic in a *SIMD* daily simulation than in a monthly *SIM* simulation. However, since this manual focuses on *SIM*, the term *month* is used in the following discussion to refer to the time step. The flow switch functions in essentially the same manner in a *SIMD* simulation with a daily time step.

The flow switch *FS* record activates a feature allowing *IF* record instream flow targets, *WR* record diversion, hydropower, or storage targets, *LO* record stream flow depletion limits, or *OR* record reservoir release limits to be switched on/off or otherwise adjusted depending on whether the volume of a selected *FSV* variable in the current and/or any number of preceding months meets a specified criterion. The *FS* record target setting rules are based on specifying two different factors which may be 1.0 or 0.0 (on-or-off switch) or any other numbers. An intermediate target or limit quantity for the current month is multiplied by one of the two alternative factors depending on conditions during any specified number of preceding months.

The flow switch defined by a *FS* record consists of the following components.

- flow switch variable *FSV*
- a criterion based on values of the specified *FSV* during the current month (day) and a specified number of preceding months (days) of the simulation
- two multiplier factors of which one or the other is applied to the water right target, stream flow depletion limit, or reservoir release limit in the current month (day) depending on whether or not the criterion is met

Any control point or water right in the *SIM* input dataset can be selected for defining a flow switch regardless of the location of the water right to which the flow switch is applied. One of the eleven variables listed on the preceding page is selected as the flow switch variable *FSV*. Two multiplier factors are specified on the *FS* record. The first factor is applied if the flow switch criterion is met. The second factor is applied if the criterion is not met. The two multiplier factors may be set at 1.0 and 0.0 to act as a switch which is completely on or off. However, the factors can be any numbers entered by the model-user on a *FS* record.

As an example, assume an instream flow target is activated only if the total regulated flow over the past six months at a particular control point falls within a certain range. The instream flow target for the current month of the simulation is initially set based upon the *IF* record and supporting records. If the regulated flow at the specified control during the past six months falls within the specified range, the target is multiplied by a factor of 1.0. Otherwise, the target is multiplied by a factor of 0.0.

A *FS* record flow switch is applied as step 8 or step 9 of the 12-step target building process outlined on pages 122-124. A flow switch is expressed as follows.

$$X2 = X1 \times FSV(FS,1) \quad \text{if the criterion is satisfied}$$

$$X2 = X1 \times FSV(FS,2) \quad \text{if the criterion is not satisfied}$$

where: *FSV(FS,1)* and *FSV(FS,2)* are factors from *FS* record fields 5 and 6.

X1 is the intermediate value of an *IF* record instream flow target, *WR* record diversion, hydropower, or storage target, *LO* record stream flow depletion limit, or *OR* record reservoir release limit that has been computed prior to applying the *FS* record flow switch based on specifications from *WR*, *IF*, *UC*, *DI/IS/IP/IM*, *BU*, *SO*, *TO*, *TS*, *CV*, and/or other *FS* records.

X2 is the next intermediate value or final value of the target or limit quantity being determined for that time period (month or day).

Alternative Criteria for Defining a Flow Switch

The criterion for applying a flow switch is selected by the entry for the parameter *FSI(FS,2)* in *FS* record field 9. The *FSI(FS,2)* options are as follows.

0 – The default is to not apply the flow switch to make water management decisions in the simulation. The *FSV* is accumulated and counts performed solely for purposes of providing information. Program *TABLES* 2FSV and 2FSC routines can be applied to organize the results if the *FS* record is used with an instream flow *IF* record right.

1 – The flow switch is based on whether the cumulative total volume of the flow switch variable *FSV* falls within the range defined by specified lower and upper bounds.

2 – The flow switch is based on counting the number of times that the monthly volume of the *FSV* falls within the range defined by specified lower and upper bounds.

3 – The flow switch is based on comparing the current or most recent monthly volume of the flow switch variable *FSV* with the preceding cumulative total volume as a measure of increases or decreases in the *FSV*.

With the default blank *FS* record field 9 (*FSI(FS,2)*=0), the cumulative *FSV* volumes used with options 1 and 2 are computed and the counts used with option 2 are made even though the flow switch is not actually applied. For an *IF* record right, these data are recorded in the *SIM* output file and read by the 2FSV and 2FSC record routines in *TABLES*. These data can also be recorded in the message file with either a *WS* or *FS* record water right. Thus, the extent to which the criterion is satisfied can be assessed without actually applying the *FS* record flow switch.

With *FSI(FS,2)* options 0, 1, and 2, a range of *FSV* volume is defined by specifying upper and lower bounds *FSX(FS,3)* and *FSX(FS,4)* in *FS* record fields 7 and 8.

$$\text{lower } FSV \text{ volume bound} \leq FSV \text{ volume} \leq \text{upper } FSV \text{ volume bound}$$

The *FSV* volume and bounds are cumulative volumes summed over the specified number of months for option 1, single-month monthly volumes for option 2, and both for option 0.

The option 1 criterion is whether the total cumulated *FSV* volume during the specified current and/or specified preceding months falls within the range defined by these lower and upper bounds. In each month of the simulation, the cumulated *FSV* volume over the specified period of time either does or does not fall within the specified range. The initial or intermediate target or limit quantity is multiplied by *FSX(FS,1)* from *FS* field 5 if the criterion is met. Otherwise, the multiplier factor *FSX(FS,1)* from *FS* record field 6 is applied.

With *FSI(FS,2)* option 2 for defining a switch criterion, the *FSV* volume is defined as the flow volume in an individual month. In each month of the specified period, the flow volume either does or does not fall within the specified volume range. The number of months during which the flow is within the range is counted. This count is applied with the following criteria defined by upper and lower count bounds specified in *FS* record fields 10 and 11.

$$\text{lower count bound} \leq \text{count} \leq \text{upper count bound}$$

Count is the number of months during which the *FSV* flow volume falls within the volume bounds. The specified lower and upper count bounds have units of time steps (months or days). The flow switch criterion is whether count falls within the specified bounds. Either multiplier factor *FSX(FS,1)* or *FSX(FS,2)* depending on whether the count falls within the bounds.

With *FSI(FS,2)* option 3, the flow switch criterion is based on whether and how much the *FSV* variable is increasing or decreasing. The flow switch continues to be defined as

$$X2 = X1 \times FSV(FS,1) \quad \text{if the criterion is satisfied}$$

$$X2 = X1 \times FSV(FS,2) \quad \text{if the criterion is not satisfied}$$

However, with option 3, the *FSX(FS,3)* and *FSX(FS,4)* entered in *FS* record fields 7 and 8 are applied by *SIM* as multiplier factors rather than bounds. *FSX(FS,3)* and *FSX(FS,4)* both default to 1.0. The option 3 criterion is as follows.

$$Y2 \times FSX(FS,3) \leq Y1 \times FSX(FS,4)$$

Y1 is the cumulative volume of the *FSV* variable summed over the specified preceding months. Y1 does not include the current month. Y2 is the volume of the *FSV* variable in the current month. Thus, with option 3 activated:

$$FSX(FS,1) \text{ is adopted if:} \quad Y2 \times FSX(FS,3) \leq Y1 \times FSX(FS,4)$$

$$FSX(FS,2) \text{ is adopted if:} \quad Y2 \times FSX(FS,3) > Y1 \times FSX(FS,4)$$

With defaults of 1.0 for *FSX(FS,3)* and *FSX(FS,4)* and the number of preceding months *FSI(FS,5)* set at one, the criterion is whether or not the *FSV* is increasing.

Recording FS Record Flow Switch Simulation Results

Targets and target shortages are recorded in output files as described in Chapter 5 along with the other simulation results. Additional data created by *FS* records can also be recorded in the *SIM* or *SIMD* output files. For the first or only *FS* record connected to an *IF* record, two variables are recorded for each month of the simulation in the last two fields of the instream flow output record in the *SIM* OUT, SOU, and DSS output files described in Chapters 5 and 6. These two variables are tabulated with *TABLES* using the 2FSV and 2FSC time series records.

- The first variable is the total cumulative volume of the flow switch variable *FSV* during the specified sequence of time periods.
- The second variable is the count of the number of months of the specified time sequence during which the *FSV* monthly volume fell within the defined range.

Thus, the extent to which the *FSI(FS,2)* options 1 and 2 criterion are satisfied during the simulation can be assessed without the *FS* record flow switch actually affecting water management decisions in the simulation. The *SIM FS* record can be combined with *TABLES* 2FSV and 2FSC records to tabulate accumulated flow volumes and monthly volume counts without basing operating decisions in the *SIM* model on the criteria. *FS* records may be attached to *IF* records that have a target of zero and thus no effect on water management/use decisions. The flows are accumulated and counted without affecting the simulation. The volumes and counts can be tabulated with *TABLES*.

The flow switch computations for a *WR* or *IF* record target can also be explored by listing simulation results in the message file. The MSS file tabulation includes the following variables.

year and month
water right identifier from the *WR* or *IF* record
integer *FS* record identifier
lower and upper bounds on flow volume from the *FS* record
simulated total cumulative volume of the *FSV*
count of months that the FSV volume was within specified bounds
final computed target

Cumulative Volume CV Record Options

The *CV* record is similar to the *FS* record but applies a different set of options to develop targets, depletion limits, and release limits. The variables *CVV* and *FSV* selected in *CV* and *FS* record field 3 are defined identically the same. The eleven *CVV* or *FSV* variable choices are listed on page 128. The time period over which the volume of the selected variable is summed is defined in the same manner. However, the *CV* record has a different set of options for applying the cumulative volume than the *FS* record. The cumulative volume of the selected *CVV* variable can be arithmetically manipulated and combined with preceding intermediate targets. Operations may be based on whether the *CVV* volume falls within specified bounds.

Parameters entered on the *CV* record control the converting of the *CVV* variable cumulative volume quantity *CVX* to the quantity X representing a *IF* record instream flow target, *WR* record diversion, hydropower, or storage target, *LO* record stream flow depletion limit, or *OR* record reservoir release limit, or (in combination with other records) an intermediate component in the development thereof. The computations proceed as follows.

The first intermediate value of X is computed with multiplication (default = 1.0) and addition (default = 0.0) factors *FSX(1)* and *FSX(2)* entered in the *CV* record fields 5 an 6.

$$X = FSX(1) \times CVX + FSX(2)$$

Optional lower and upper bounds *FSX(3)* and *FSX(4)* entered in *CV* record fields 7 and 8 are applied as specified by the parameter *FSI(2)* in *CV* record field 9. The default *FSI(2)* option 1 is to not apply the limits at all. *FSI(2)* option 2 consists of applying the bounds as follows.

If [X < *FSX(3)*] then X is changed to *FSX(3)*
If [X > *FSX(4)*] then X is changed to *FSX(4)*

Alternatively, with *FSI(2)* option 3, *SIM* applies the lower and upper bounds *FSX(3)* and *FSX(4)* as follows in developing the target, depletion limit, or release limit X.

If [X < *FSX*(3)] then X is changed to zero
If [X > *FSX*(4)] then X is changed to zero

FSI(2) option 4 in *CV* record field 9 is based on VX_{T-1} and VX_{T-2} which are the values of the *CVV* variable one day and two days before the current day of the simulation. Limits *FSX*(3) and *FSX*(4) from the *CV* record are defined in terms of ratio R which is a measure of the rate that the *CVV* variable changed between the preceding two days. For example, for a target X being set for Friday, R of 1.25 represents a 25% flow increase between Wednesday and Thursday.

$$R = \frac{VX_{T-1}}{VX_{T-2}}$$

If [R < *FSX*(3)] then X is changed to zero
If [R > *FSX*(4)] then X is changed to zero

An *IF* or *WR* record target or *LO* or *OR* record limit may be developed prior to the *CV* record by *IF*, *WR*, *UC*, *TO*, *TS*, *FS*, *DI/IS/IP*, *BU*, *WS*, *OR*, and/or other *CV* records. An option for combining this preceding target or limit (X) with the X computed with this *CV* record is selected in *CV* record field 10. The options are as follows.

Option 1 – The X computed by the *CV* record is its final product, with no use of a preceding target.
Option 2 – The X computed by the *CV* record is added to the preceding target.
Option 3 – The smallest of either X or the preceding target is adopted.
Option 4 – The greatest of either X or the preceding target is adopted.
Option 5 – The preceding target is adopted if X falls with specified bounds. Otherwise, X is adopted.
Option 6 – The preceding target is adopted if X falls with specified bounds. Otherwise, zero is adopted.

In a given month of the *SIM* simulation, the final product resulting from the *CV* record operations is a monthly volume, in units such as acre-feet/month, that represents either an *IF* record instream flow target, *WR* record diversion, hydropower, or storage target, *LO* record stream flow depletion limit, or *OR* record reservoir release limit. *SIMD* allows daily or other sub-monthly time step quantities. The quantity produced by the *CV* record may be the actual target or limit adopted for that month of the simulation or an intermediate amount subject to further adjustment by *WR*, *IF*, *SO*, *TO*, *FS*, *CV*, *TS*, and *DI/IP/IS/IM* record routines.

An option activated by *FSI(FS,9)* in *FS* field 15 lists the following quantities in the message MSS file summarizing the *CV* record computations for a *WR* or *IF* record target.

year and month
WR or *IF* record water right identifier
integer *CV* record identifier
preceding target
CVV variable total cumulative volume *CVX*
final computed target

FS and CV Record Operations in the Priority Sequence

Inclusion of the current month in the summation of a selected flow switch variable *FSV* or cumulative volume variable *CVV* is complicated by the fact that *FSV* and *CVV* quantities change during the priority sequence simulation computations. One of the 11 variables listed on page 128 is selected in *FS* or *CV* record field 3 as the *FSV* and *CVV*. The first six variables refer to a control point. The last five choices are connected to a water right. For *FSV*/*CVV* options 7, 8, 9, 10, and 11, for which the variable to be accumulated refers to a water right, the volume in the current month is included in the summation only if the referenced water right is senior to *FS* or *CV* record water right. For options 1-6 which refers to a control point, the latest preceding value computed in the priority sequence based simulation is adopted for the current month.

FSI(FS,8) specifies whether the current month is included or excluded in the *FSV/CVV* summation. *FSI(FS,8)* option 3 consists of excluding the current month. *FSI(FS,8)* options 1 and 2 include the current month. Options 1 versus 2 are slightly different if regulated flow is the *FSV* or *CVV* but are identically the same for any other choice of variable. With regulated flow selected for the *FSV* or *CVV*, option 1 differs from option 2 only if the second pass option is activated by *PASS2* in *JO* record field 10 or *IFMETHOD* in *IF* record field 7. With the default *FSI(FS,8)* option 1, during the second pass, the regulated flow computed during the first pass is used. With *FSI(FS,8)* option 2, the latest regulated flow computed in the second pass is used in the same manner that the latest value computed for any other *FSV/CVV* variable would be used.

Connecting FS and CV Records with WR, IF, OR, and LO Records

Any number of *FS* and *CV* records can be provided for any of the water rights in a *SIM* input DAT file. Any number of water rights can apply the same *FS* or *CV* record.

SIM automatically numbers *FS* and *CV* records in the sequential order (1, 2, 3, ...) in which they are found in the input file. The sequential numbering provides integer identifiers for the records. Model users can also enter the identifiers in *CV*/*FS* record field 2 to allow convenient identification of different *CV* and *FS* records when users read the input file. All *CV* and *FS* records are included together in the same sequential numbering with no differentiation between *CV* versus *FS* records. *WR* record field 10, *IF* record field 9, and *OR* record field 10 reference these integer identifiers.

FS and *CV* records can be employed in the following alternative modes.

- Any number of *FS and CV* records can be included in the set of auxiliary records (*SO*, *TO*, *LO*, *TS*, *BU*, *PX*, and *WS/HP/OR*) belonging to a *WR* or *IF* record. These *FS* and *CV* records are applied as step 8 of the 12-step target building process outlined on pages 122-124 to develop the water right target. The sequential *FS* and *CV* record integer identifiers have no relevance in this mode of application. Quantities are computed in the priority sequence simulation in the priority specified on the *WR* or *IF* record.
- A *WR* or *IF* record can reference a *FS* or *CV* record that is located with the records for some other *WR* or *IF* record right by entering the *CV* or *FS* integer identifier on the *WR* or *IF* record. This is step 9 of the 12-step target building process outlined on pages 122-

124. The same *CV* or *FS* record results developed at the same priority can thus be applied for any number of water rights. The quantity provided by the *CV* record is a monthly target volume. Depending on *FSCV(wr)*, the *FS* record provides either a target volume or switch multiplier factor to be applied to the *WR* or *IF* record target.

- A *FS* or *CV* record can be used in setting a maximum release limit for a reservoir by entering the integer identifier of the *FS* or *CV* record on the reservoir operating rules *OR* record. The quantity provided by the *CV* record is a monthly volume for the maximum release capacity. The *FS* record provides either the actual volume of the monthly release limit or a switch multiplier factor to be applied to the release limit entered in *OR* field 9.
- A water right can be referenced in *TO* and *LO* record field 9. *TO* and *LO* records for the current right can access a target that has been computed for another right (*WR*, *IF*) using *CV, FS, UC, SO, TO, LO, TS, BU, PX, WS/HP/OR*, and *DI/IS/IP* records.

As previously discussed, water right type is specified in *WR* record field 6. Water right type 8 is for rights created solely to be referenced by *TO, LO, OR, CV*, and *FS* records as noted above. A type 8 right does nothing but compute a target volume or flow switch in the priority sequence and by itself has no effect on the simulation. However, its target can be used in *TO, LO, OR, CV*, and *FS* record operations performed for other water rights.

Water rights from Example 11B of Appendix B are reproduced below to illustrate alternative ways of connecting *FS* (or *CV*) records to *WR* and *IF* record rights. *FS* records 1 and 2 set instream flow targets for *IF* record rights *IF-IF-1* and *IF-IF-2*. *FS* records 3 and 4 are components of *IF* record rights *IF-IF-3* and *IF-IF-4* but their *FSV* is the diversion target of the *WR* record right with identifier *Type 8 Right*. *FS* record 5 is a target-setting component of *IF* record right *IF-IF-5*. *WR* record right *WR-FS-5* uses the flow switch multiplier developed by *FS* record 5 for *IF* record rights *IF-IF-5*. *WR* record right *WR-FS-5* also applies drought index 1 as well as flow switch 5 in setting its diversion target.

```
IF  CP-2   6000.            1                 IF-FS-1
FS  1  2           1.0     0.0   1500.   2500.   1         11               1
**
IF  CP-2  12000.            2   2             IF-FS-2
FS  2  2           1.0     0.0   1500.   2500.   1          5   7  12       1
**
WR  CP-2   1200.            3   8                            Type 8 Right
**
IF  CP-2  18000.            4   2             IF-FS-3
FS  3 10           1.0     0.0     50.    300.   2   0   1  11              1 Type 8 Right
**
IF  CP-2  24000.            5   2             IF-FS-4
FS  4 10           1.0     0.0     50.    300.   2   0   1   5   7  12       1 Type 8 Right
**
IF  CP-2  30000.            6   2             IF-FS-5
FS  5  1           0.0     1.0     1.0     1.0   3          1               1
**
WR  CP-1   3600.            8                          -5   1        WR-FS-5
WS Res-A  10000.
**     !       !       !       !       !       !       !       !       !       !       !
DI     1       1   Res-A
IS     4     0.0   5000.  10000.
IP           0.0     50.     50.
IM     1  -1  -1  -1  -1  -1  -1  -1  -1   0   0   0
```

River/Reservoir System Operating Rules for Meeting Water Use Requirements

Modeling river/reservoir/use system operations may range from very simple to very 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 sections. Table 4.3 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 previously discussed water right types 1-8 are fundamental in defining operating rules. The following discussion describes other 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.

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*, and *CV* 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:

$$AMTRF_{type\,4\,right} = T_{type\,4\,right} - \left(S_{previous\,right}\right)\left(RFAC_{type\,4\,right}\right)$$

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 alternate control point identifier *ACPID* entered on the *SO* record specifies the location from which flow depletions occur. 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 *WR* record field 2.

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 set of *WR*, *WS*, and *SO* records allow 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.

Limits on the stream flow depletions incurred by a *WR* record water right can also be imposed with a limit options *LO* record. The *LO* record has identically the same format as the target options *TO* record. However, the *LO* record produces maximum limits on stream flow depletions rather than *TO* record diversion, instream flow, hydropower, or storage targets. The *LO* record depletion limits are computed using the same *TO* record options that are available for developing targets. The resulting *LO* record maximum stream flow depletion limit is applied in the *SIM* simulation in the same manner as the limits established by *SO* and *ML* records.

Reservoir Operations

Reservoir storage parameters are provided on the storage *WS* record associated with a water right. Any number of water rights can be associated with a single reservoir. Any number of reservoirs may be associated with a single water right. 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. Reservoir operations are defined by water right type specified on *WR* records and rules specified on operating rules *OR* records along with parameters on *WS*, *HP*, and other records. Storage capacities are specified as follows.

The top of the inactive pool is specified on the *WS* record. Each individual right associated with a reservoir has its own inactive pool. No releases or diversions occur from an inactive pool. The reservoir storage level is allowed to fall below the top of inactive pool only due to evaporation.

The *WS* record includes the total storage capacity volume at the top of conservation pool. The *MS* record allow the conservation storage capacity to vary monthly. Water right type 7 on the *WR* record allows the storage capacity to be computed as a target. *SIM* has no features for modeling flood control operations. When a reservoir is full to capacity, outflow equals inflow. *SIMD* allows gated or ungated flood control or surcharge storage capacity above the top of conservation pool to be included in the simulation as described in the *Daily Manual*.

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.

<u>Multiple-Reservoir and Multiple-Right Reservoir Systems</u>

A *WRAP-SIM* water right may include: (1) maintaining (refilling) the storage in one reservoir and (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).

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. 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.

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. A maximum release capacity can be specified on the *OR* record or computed by an *OR* record reference to a *FS* or *CV* record.

The cumulative total storage capacity below the top of conservation pool is specified in *WS* record field 3. A type 7 water right refills storage based on a storage target computed in the same way as a diversion target. This water right type 7 storage target is the conservation storage capacity to be filled subject to the constraint of not exceeding the capacity specified in *WS* record field 3. Seasonal rule curve operations are modeled with monthly storage *MS* 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. The reservoir is refilled to the *WS* record field 3 storage capacity subject to the constraint of not exceeding the capacity limit for that month specified on the *MS* record.

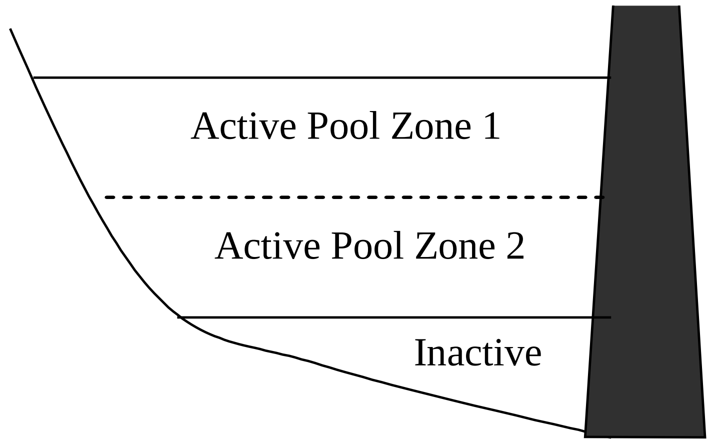

Figure 4.1 Reservoir Pools and Zones

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. (Refilling occurs only with type 1 right.) 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 maximum release capacity or to flag pipeline conveyance. The optional *OR* record includes the reservoir control point location, storage capacity at top of zone 2, zones 1 and 2 release ranking factors, specification of gravity flow versus pipeline flow, and a maximum release capacity or reference to a *FS* or *CV* record. The *OR* record is not required if defaults are adopted for all of its parameters.

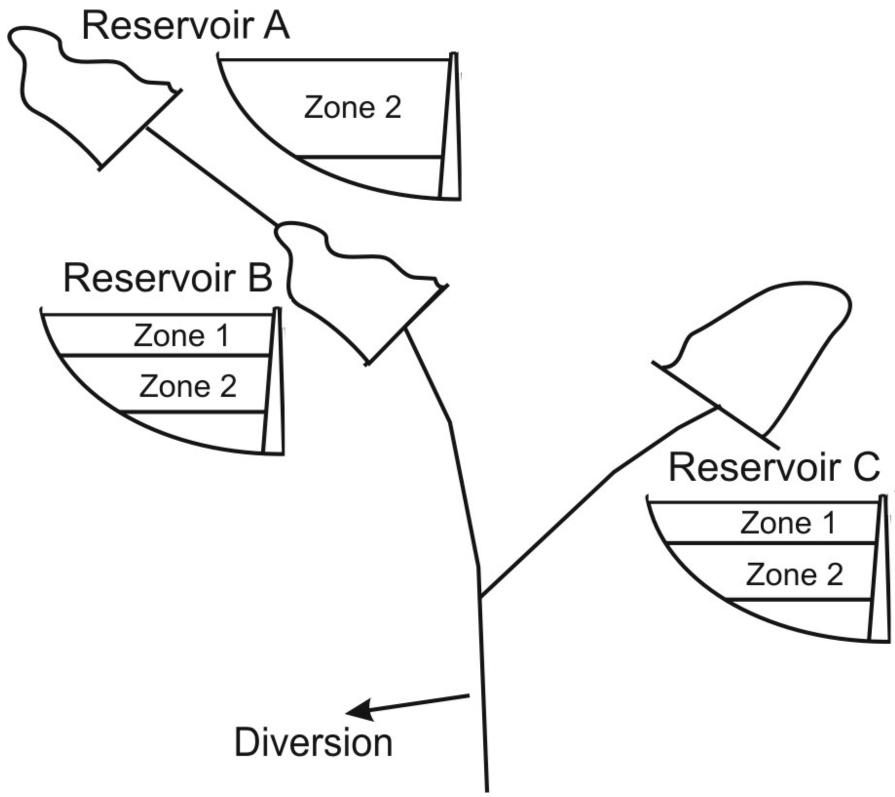

Figure 4.2 Storage Zones for Defining Multiple-Reservoir Release Rules

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.

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.

$$\text{rank index} = (\text{multiplier factor}) \left[\frac{\text{storage content in zone}}{\text{storage capacity of zone}} \right] + \text{addition factor} \qquad (4.5)$$

Equation 4.5 can be written more concisely as:

$$\text{rank index} = M \left[\frac{\text{content}}{\text{capacity}} \right] + A \tag{4.6}$$

where *M* and *A* for zones 1 and 2 are four factors entered on the *OR* record. 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. Application of the rank index is explored in Example 9.

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.

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.

Other Optional Features

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.

A maximum allowable monthly release limit for a reservoir may be specified in *OR* record fields 9, 10, and 11. A constant release limit may be specified, or alternatively the release limit can be varied with flow or other conditions using a flow switch *FS* or cumulative volume *CV* record and associated records. The limit could represent either outlet structure capacity or operating rules.

Reservoir releases meet diversion requirements at the control point of the reservoir or at control points located downstream of the reservoir by default. Downstream releases are assumed to reach the diversion site by gravity flow in the stream channel. *OR* record field 6 provides the alternative of modeling a pipeline or canal with pumps as needed 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.

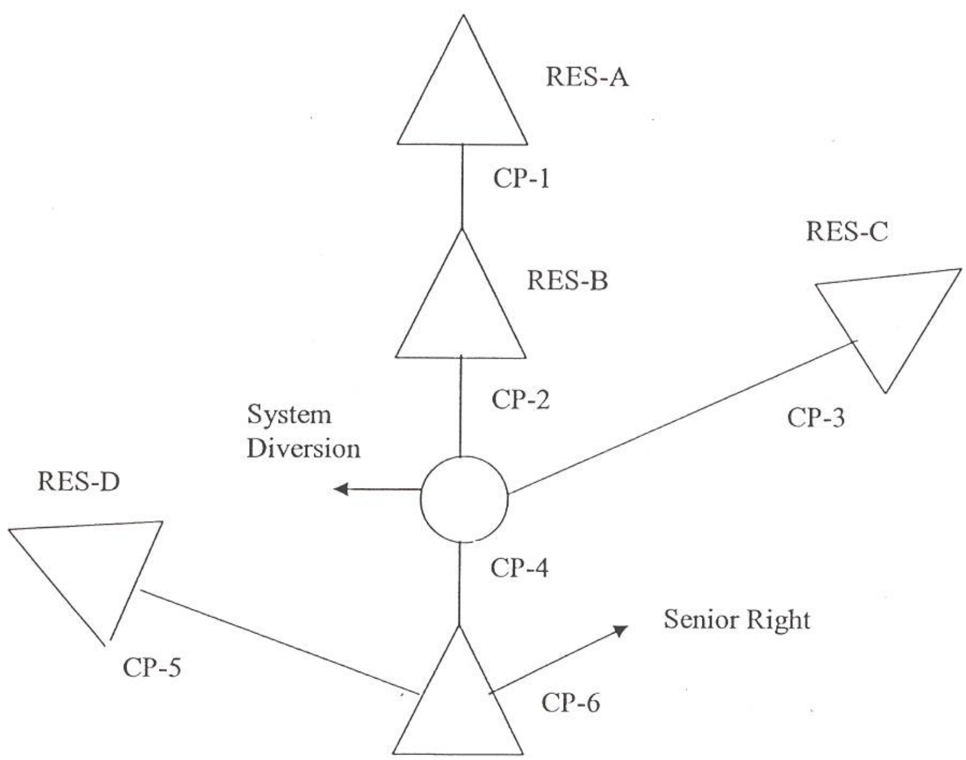

Figure 4.3 Multiple Reservoir System

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.

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 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 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.

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 evaporation volume is allocated between the different entities in direct proportion to their beginning-of-month and end-of-month storage contents.

2. 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.

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.

<u>Evaporation Allocation Methodologies Activated by the EA Record</u>

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 as illustrated by Appendix B Example 8.

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. *<u>Incremental Based on Water Right Priorities</u>*.- 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. *<u>Proportional to Storage Content</u>*.- 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. *<u>User-Specified Factors</u>*.- 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.

<u>Multiple Rights at the Same Component Reservoir</u>

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

$$\text{adjusted available stream flow} = MIN + (A_1 - MIN) \times AFX$$

- 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.

<u>Dual Simulation Options</u>

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 *RG* record can be used to assign the same *PX* record parameters to groups of rights as described later in this chapter.

The DUAL simulation 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, 5, and 7 rights as indicated in Table 4.1), 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* field 2, *SO* field 14, or *RG* record field 4]

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 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 or *RG* fields 5 and 6]

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 appropriared 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 of 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 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.

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.

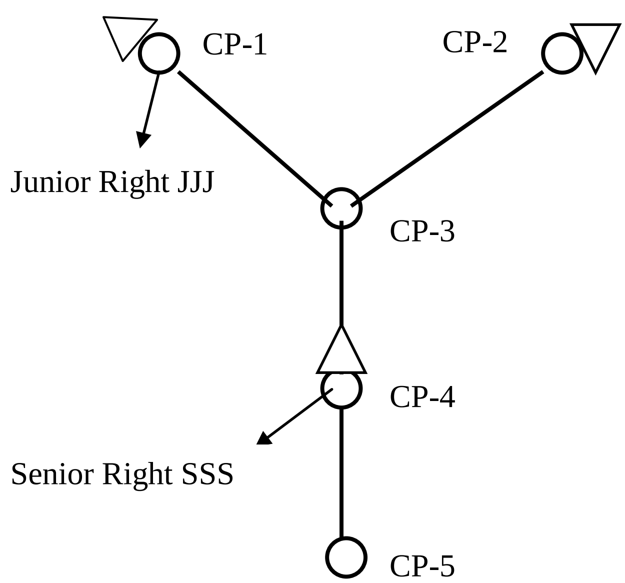

Figure 4.4 System Schematic for Example 12 in Appendix B

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 12 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 third-party water users. 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 of certain actions 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*.

Water Rights Grouping RG Record Capabilities

The *RG* record identifies all water rights that fit one or more specified criteria. A water right is included in the group defined by a *RG* record only if each and every selected criterion is satisfied by that right. Any number of *RG* records can be included in a *SIM* input DAT file defining different groups. The *RG* record grouping of water rights serves the following purposes.

- The values for the parameters for the dual simulation and downstream control point flow availability options described in the preceding section can be assigned to all rights included in the group. This provides a convenient means for using one *RG* input record to assign values for these parameters to a large number of rights without preparing individual *PX* records for each water right.

- Several *TABLES* routines deal with simulation results for groups of water rights in the *SIM* datasets which are defined by group identifiers. Two optional water right group identifiers can be assigned to water rights by entering identifiers in the appropriate fields of each individual *WR* or *IF* record. Alternatively, a group identifier can be assigned by the *RG* record to all water rights in a defined group.

- Information describing the selected water rights can be listed in the message MSS file. Thus, in working with a large *SIM* input dataset, water rights meeting certain criteria of interest can be conveniently identified and viewed.

The following types of criteria for defining groups of water rights can be specified on a *RG* record.

- either *WR* record or *IF* record rights or both types
- water right type specified on *WR* record
- lower and upper limits on the annual target amount specified on *WR* or *IF* record

- lower and upper limits on reservoir storage capacity specified on *WS* record
- lower and upper limits on the priority number specified on *WR* record
- inclusion or exclusion of groups defined by *WR* record group identifiers
- location of the water right in a specified river reach or subbasin

River reaches or subbasins are delineated by specifying downstream and upstream control points. The larger TCEQ WAM System datasets for which the *RG* record is designed contain hundreds of control points. However, Figure 2.1 on page 18 provides a simple example with 12 control points. With control point 7 of Figure 2.1 specified on the *RG* record as the downstream control point limit and no upstream limits specified, the group includes water rights located at control points 1, 2, 3, 4, 5, 6, and 7. With control point 4 as the downstream control point limit and no upstream limits specified, the group includes water rights located at control points 3 and 4. With control points 2, 5, and 9 specified as lower limits but no upper limits specified on the *RG* and *RG2* records, , the group includes water rights located at control points 1, 2, 3, 4, 5, 8, and 9.

The following options are provided by the *RG2* record for defining upstream limits.

1. listing of control points at which the water right can not be above
2. listing of control points of which the water right must be at or below at least one

Assume that the downstream control point limit in Figure 2.1 is control point 10 and the upstream limits are listed on the *RG* record as being control points 2 and 9. With option 1 above for defining upstream limits, the group contains all water rights located at control points 2, 3, 4, 5, 6, 7, 9, and 10. Water rights at control points 1, 8, 11, and 12 are excluded from the group. With option 2 for defining upstream limits, the group contains all water rights located at control points 2, 6, 7, 9, and 10. Control points 3, 4, and 5 met the option 1 upstream limit criterion but do not meet the option 2 upstream limit criterion.

Period-of-Analysis Input Sequences of Water Right Targets, Stream Flow Depletions, and Reservoir Storage Capacities

SIM options allow quantities for certain variables normally computed by the simulation model to be entered as input for each month of the simulation period-of-analysis rather than computed. These variables include diversion and instream flow targets, limits on stream flow depletions, and reservoir storage capacity limits.

Water Right Targets

Water supply diversion and reservoir storage targets associated with a water right *WR* record or instream flow targets associated with a *IF* record may be provided in a *SIM* input DAT file on target series *TS* records. Example 7 in Appendix B includes *TS* records for instream flow and diversion requirements. Targets on *TS* records are input for each month of the simulation. This feature allows quantities computed in a prior simulation or observed gaged data to be entered as fixed targets rather than computed within the *SIM* simulation. The input *TS* record target sequences can also be combined with other *SIM* features for setting targets.

Maximum Limits on Stream Flow Depletions

A period-of-analysis sequence of limits on stream flow depletions may also be entered on *TS* records. The values may vary in each month of the simulation. This feature allows the combined diversion and storage refilling amounts allowed for a particular water right to be limited to not exceed amounts determined by a prior simulation reflecting specified conditions of water resources development, management, and use. The procedure for modeling subordination agreements outlined in the preceding section of this chapter incorporates this concept.

Reservoir Storage Capacity Limits

Reservoir storage capacity limits may be entered in the *SIM* input DAT file as observed storage *OS* records, which are designed primarily for use in adjusting gaged stream flows to develop naturalized flows as described in the *Hydrology Manual*. Sequences of actual observed storage levels or storage volumes computed in a prior simulation are entered on *OS* records.

OS records provide storage volumes for each individual month of the hydrologic period-of-analysis for a particular reservoir. In each month of the simulation, as each water right is considered in the priority sequence, the storage capacity of the reservoir is the lesser of the storage capacity specified for the water right on its *WS* record and the volume specified for the reservoir on its *OS* record. The reservoir is filled to the capacity defined by the *WR/WS* and *OS* records subject to being constrained to the amount of stream flow available for filling. The end-of-month storage volume contained in the reservoir is limited to not exceed its capacity. Excess storage is released as a spill which is cascaded downstream just as any other reservoir release.

The features activated by observed storage *OS* records and the monthly storage *MS* record described earlier in this chapter are similar with certain distinct differences. Both the *MS* and *OS* records set monthly-varying limits on reservoir storage capacity. In each month of the simulation, as each water right is modeled, the reservoir storage capacity is the lesser of the volume set by the *WR/WS* records for the water right and the *MS* and/or *OS* records for the reservoir. *MS* and *OS* record features differ as follows.

- *MS* records are designed to model seasonal rule curve reservoir operations characterized by a designated top of conservation pool elevation that varies during the 12 months of the year. *OS* records are designed to simulate time series of either actual observed reservoir storage volumes or storage volumes previously determined with a simulation model for specified conditions of water resources, development, allocation, management, and use.

- Storage volumes are entered on a *MS* record for each of the 12 months of the year. These storage capacity limits are applied in each year of the simulation. Storage volumes are entered on *OS* records for each month of the simulation period-of-analysis. *OS* records are required for each year of the period-of-analysis.

- The storage capacity on a *MS* record is for an entire month from the beginning to the end of the month. Spills occur at the beginning of the month as necessary to prevent the storage capacity from being exceeded. *OS* records contain end-of-month storage volumes. End-of-month reservoir releases (spills) prevent the storage capacity from being exceeded.

CHAPTER 5
ORGANIZATION AND ANALYSIS OF SIMULATION RESULTS

This chapter describes the *WRAP-SIM* simulation results recorded in the OUT 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 discussed in Chapter 6 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 file and organized with *TABLES*, Chapter 6 covers the simulation results provided in the other auxiliary *SIM* output files. Chapter 7 covers CRM.

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 *Daily Manual and Salinity 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 signification 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 evaporation-precipitation depths tabulated with the *TABLES* 2EPD and 2EVR records, reservoir surface elevations associated with the 2WSE record, and 2FSC record counts.

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) – A diversion shortage for a given water right in a given month is the final diversion target less the actual diversion volume as constrained by water availability. 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.

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 for a given *IF* record right. Options for combining multiple instream flow *IF* records at the same control point include adopting the junior target, largest target, or smallest target. The target adopted by the *IF* record right at its priority in the priority sequence is recorded in the instream flow right output record. The target recorded on the control point output record is the final target at the end of the priority sequence. An option allows the target developed for an *IF* record to be applied at multiple control points. The target will be on the OUT file output records of each of the multiple control points but on only one *IF* right output record.

instream flow shortage (2IFS) − An instream flow shortage is the amount by which the monthly regulated flow volume falls below the instream flow target. Shortages are recorded in instream flow output records at the priorities of the right in the priority sequence. Control point output records include instream flow targets but do not include instream flow shortages. *TABLES* computes shortages for a control point as the difference between the target volume and regulated flow volume when the regulated flow is below the target.

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, 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 number. Secondary energy is reported as a negative quantity. Shortages represent shortfalls in meeting an energy target. Secondary energy is the amount greater than the target resulting from releases through 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 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

flow volumes and counts (2FSV and 2FSC) – Flow switch *FS* record flow volumes and counts are recorded on *SIM* instream flow *IF* record right output records. The accumulated flow volume of the switch variable *FSV* is read by a *TABLES* 2FSV record. The count of the number of months of the simulation during which the monthly *FSV* volume falls within a specified range is read by a FSC record.

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 fields 4 and 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.

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.

reservoir storage capacity (2RSC) − Reservoir storage capacities are set by *WS*, *MS*, and *OS* input records from the DAT file and recorded on reservoir/hydropower records in the OUT file.

reservoir storage drawdown (2RSD) − Programs *HYD* and *TABLES* determine storage drawdowns or shortages (2RSD) by subtracting storage volume (2STO) from capacity (2RSC) read from the *SIM* OUT file.

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 or 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 otherwise selected 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 priority sequence. If other more junior rights share storage in this same reservoir, 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 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.

The instream flow *IF* record target and shortage recorded on a water right record are the quantities in effect in the priority sequence of the *IF* record right. The instream flow target on a control point output record is the final target at the end of the priority sequence.

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 *SIM* output 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.

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 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.

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.

Table 5.1
Summary of *SIM* Simulation Results Variables in OUT File Output Records

Variables Recorded in *SIM* Simulation Results OUT File	*TABLES* 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	CP field 14	IF field 11	
instream flow shortage	2IFS	field 10–field 14	IF field 12	
flow switch record volume	2FSV		IF field 13	
flow switch record count	2FSC		IF field 14	
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
reservoir storage capacity	2RSC			R/H field 13
reservoir drawdown volume	2RSD			field 13 – field 5

Table 5.2
Organization of Main SIM Output File

First Five Records of *WRAP-SIM* Output File

OUT File from WRAP-SIM (July 2011 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	2FSV	flow switch volume	F11.2
14	increase in available flow	F10.2	2XAV	2FSC	flow switch count	I4

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	F8.0	106-113	2CLC
12	channel losses	F7.0	114-120	2CLO
13	upstream reservoir releases	F8.0	121-128	2URR
14	instream flow target	F8.1	129-136	2IFT

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	reservoir storage capacity	F9.1	128-136	2RSC

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.

Table 5.6
Beginning of OUT File for Example in *Fundamentals Manual*

```
WRAP-SIM (August 2012 Version) OUT Output File
  File FundExam.DAT
  SIM Input File for the Example in the Fundamentals Manual
  July 2010
  1940   58   11   29    6    0    0    0  1.000
IF   1      0.00      0.00      0.00      0.00      0.00      0.00      0.00          IF-1     305.75      0.00      0.00  0
IF   1      0.00      0.00      0.00      0.00      0.00      0.00      0.00          IF-2   10191.78      0.00      0.00  0
1940 1     0.000  3900.000    629.21 100736.79   1166.00   1166.00      0.00          WR-6WacoLake            1365.00      0.00
1940 1     0.000   637.000   2594.50 570240.00   3231.50  10094.00      0.00          WR-1       PK            222.95      0.00
1940 1     0.000 13256.514   2583.06 563857.44   6862.50   6862.50      0.00          WR-2       PK              0.00      0.00
1940 1     0.000    56.500      0.00      0.00     56.50   3920.25      0.00         WR-14 Cameron              5.65      0.00
1940 1     0.000   172.500      0.00      0.00    172.50  10306.51      0.00         WR-20   Bryan              8.62      0.00
1940 1     0.000   248.000      0.00      0.00    248.00  11186.58      0.00         WR-22    Hemp              0.00      0.00
1940 1     0.000   161.500      0.00      0.00    161.50   2952.04      0.00         WR-16WacoGage              0.00      0.00
1940 1     0.000   224.000      0.00      0.00    224.00   4140.74      0.00         WR-17Highbank              0.00      0.00
1940 1     0.000  1055.600      0.00      0.00   1055.60   3863.75      0.00         WR-13 Cameron            527.80      0.00
1940 1     0.000  2262.000      0.00      0.00   2262.00   8737.90      0.00         WR-19   Bryan           1470.30      0.00
1940 1     0.000  5544.800      0.00      0.00   5544.80   7371.92      0.00         WR-21    Hemp              0.00      0.00
1940 1     0.000  5379.400   1147.17 452069.44    996.00    996.00      0.00          WR-8  Belton           2420.73      0.00
1940 1     0.000  5275.551   1142.34 446798.72      0.00      0.00      0.00          WR-9  Belton           1055.11      0.00
1940 1     0.000  1666.316    134.12  35455.56    156.00    156.00      0.00         WR-10  George            799.83      0.00
1940 1     0.000  2732.733    421.03  63493.31   1147.08   1147.08      0.00         WR-11 Granger           1093.09      0.00
1940 1     0.000  1170.000   1795.35 625703.62   1569.01   1569.01      0.00          WR-3 Whitney            468.00      0.00
1940 1   460.500   460.500      0.00      0.00      0.00      0.00      0.00         WR-12 Cameron              0.00      0.00
1940 1  1652.653  1652.653      0.00      0.00      0.00      0.00      0.00         WR-18   Bryan              0.00      0.00
1940 1     0.000  1352.000    869.22 187144.78      0.00      0.00      0.00          WR-7WacoLake             540.80      0.00
1940 1     0.000  5725.726      0.00      0.00      0.00      0.00   5725.73         WR-15 SystemC           2004.00      0.00
1940 1   372.500   372.500      0.00      0.00      0.00      0.00      0.00         WR-23    Hemp              0.00      0.00
1940 1     0.000 58558.559      0.00      0.00      0.00      0.00  58558.56         WR-24 SystemH              0.00      0.00
1940 1     0.000     0.000   1795.35 625703.62      0.00      0.00      0.00          WR-5  Refill              0.00      0.00
1940 1     0.000     0.000   2434.29 497885.97      0.00      0.00      0.00         WR-25  Refill              0.00      0.00
1940 1     0.000     0.000   1136.93 440913.44      0.00      0.00      0.00         WR-26  Refill              0.00      0.00
1940 1     0.000     0.000    134.12  35455.56      0.00      0.00      0.00         WR-27  Refill              0.00      0.00
1940 1     0.000     0.000    421.03  63493.31      0.00      0.00      0.00         WR-28  Refill              0.00      0.00
    PK     0.000 13893.514   2434.29 497885.97  10094.00      0.00      0.00  10094.00  66120.23   616.  4033.  66120.    0.0
  Whit     0.000  1170.000   1795.35 625703.62   1569.01      0.00      0.00  11746.00  62785.62    99.   559.  62087.    0.0
 WacoL     0.000  5252.000    869.22 187144.78   1166.00      0.00      0.00   1166.00      0.00     0.     0.      0.    0.0
 WacoG     0.000   161.500      0.00      0.00    161.50      0.00      0.00  13511.00  62763.77   123.   615.  61528.    0.0
  High     0.000   224.000      0.00      0.00    224.00      0.00      0.00  14754.00  63290.24   173.   853.  60913.    0.0
Belton     0.000 10654.951   1136.93 440913.44    996.00      0.00      0.00    996.00   5890.66    28.   165.   5891.    0.0
George     0.000  1666.316    134.12  35455.56    156.00      0.00      0.00    156.00      0.00     1.     0.      0.    0.0
 Grang     0.000  2732.733    421.03  63493.31   1147.08      0.00    799.83    502.00      0.00    20.    12.      0.    0.0
 Camer   460.500  7298.326      0.00      0.00   1112.10      0.00   1093.09   4226.00   2744.41   121.    68.      0.  305.8
 Bryan  1652.653  4087.153      0.00      0.00   2434.50      0.00      0.00  20668.00  64661.98   447.  1547.  60060.    0.0
  Hemp   372.500 64723.859      0.00      0.00   5792.80      0.00      0.00  31649.00  10191.78     0.     0.      0. 10191.8
    PK      0.00      0.00   2434.29 497885.97  10094.00      0.00  80013.75      0.00    0.1590    0.1590     0.000 570240.0
  Whit  -3024.87   5274.87   1795.35 625703.62   1569.01      0.00   1170.00      0.00    0.0770    0.0770   533.664 627100.0
 WacoL      0.00      0.00    869.22 187144.78   1166.00      0.00   5252.00      0.00    0.1070    0.1070     0.000 192100.0
Belton      0.00      0.00   1136.93 440913.44    996.00      0.00  16545.62      0.00    0.0940    0.0940     0.000 457600.0
George      0.00      0.00    134.12  35455.56    156.00      0.00   1666.32      0.00    0.1040    0.1040     0.000  37100.0
 Grang      0.00      0.00    421.03  63493.31   1147.08      0.00   2732.73      0.00    0.0970    0.0970     0.000  65500.0
IF   2      0.00      0.00      0.00      0.00      0.00      0.00      0.00          IF-1     276.16      0.00      0.00  0
IF   2      0.00      0.00      0.00      0.00      0.00      0.00      0.00          IF-2    9205.48      0.00      0.00  0
1940 2     0.000  3780.000     41.26 101593.74   1315.00   1315.00      0.00          WR-6WacoLake            1323.00      0.00
1940 2     0.000   617.400    792.62 506647.94  10172.00  10172.00      0.00          WR-1       PK            216.09      0.00
1940 2     0.000 14729.459    783.00 491928.12      0.00      0.00      0.00          WR-2       PK              0.00      0.00
1940 2     0.000    90.400      0.00      0.00     90.40  24789.68      0.00         WR-14 Cameron              9.04      0.00
1940 2     0.000   276.000      0.00      0.00    276.00  38673.53      0.00         WR-20   Bryan             13.80      0.00
1940 2     0.000   396.800      0.00      0.00    396.80 139121.64      0.00         WR-22    Hemp              0.00      0.00
1940 2     0.000   258.400      0.00      0.00    258.40    565.20      0.00         WR-16WacoGage              0.00      0.00
1940 2     0.000   358.400      0.00      0.00    358.40   6431.24      0.00         WR-17Highbank              0.00      0.00
1940 2     0.000  1401.400      0.00      0.00   1401.40  24699.28      0.00         WR-13 Cameron            700.70      0.00
1940 2     0.000  3003.000      0.00      0.00   3003.00  36440.96      0.00         WR-19   Bryan           1951.95      0.00
1940 2     0.000  7361.200      0.00      0.00   7361.20 133889.28      0.00         WR-21    Hemp              0.00      0.00
1940 2     0.000  5213.880   -523.71 437886.28   1663.00   1663.00      0.00          WR-8  Belton           2346.25      0.00
1940 2     0.000  5861.723   -521.19 432022.03      0.00      0.00      0.00          WR-9  Belton           1172.34      0.00
1940 2     0.000  1615.045   -114.03  35274.55   1320.00   1320.00      0.00         WR-10  George            775.22      0.00
```

Water Right Output Records

Water rights in WRAP may be defined by either a water right *WR* record or instream flow *IF* record in the *SIM* input DAT file. Likewise, water right output records in the *SIM* output OUT file may be for either *WR* or *IF* record rights. 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.

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. 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, 3F11.2, I4)

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. Fields 13 and 14 are nonzero only if a flow switch *FS* record is connected to the *IF* input record.

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 *SIM* output OUT file are grouped together for a given month. The 136-character record contains 14 variables stored in the format indicated by the following Fortran format statement.

Format (A6, 2F11.3, 7F11.2, F8.0, F7.0, F8.0, F8.1)

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. Field 13 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. The final and most junior instream flow target at this control point is recorded in the last field.

Reservoir/Hydropower Output Records

Each reservoir/hydropower output 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 which in always a month in SIM but may be a sub-monthly time step in SIMD.

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 13 variables stored in the following format.

Format (A6, 2F11.3, 6F11.2, 2F11.4, F11.3, F9.1)

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.

Table 5.7
Outline of Program *TABLES* Features

TABLES Features Covered in Chapter 4 of the *Users Manual*

Auxiliary: IDEN, DATA, COMM, PAGE, TITL, TEST, FILE, UNIT, ENDF

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 (4HRR) and *SIM* priority sequence flow availability ZZZ file (4ZZZ and 4ZZF).

Type 5: Conditional reliability tables developed from *SIM* or *SIMD* CRM file as discussed in Chapter 7 (5CRM, 5CR1, 5CR2, 5COR).

TABLES Features Covered in the *Daily and Salinity Manuals*

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).

Chapter 4 of the *Users Manual* explains *TABLES* types 1, 2, 3, 4, and 5 input records and resulting output tables or listings. The *Daily and Salinity Manuals* provide instructions for applying *TABLES* types 6, 7, and 8 records. The following general description of types 1, 2, 3, and 4 is followed by a more in depth presentation of capabilities provided by *TABLES* type 2 options for organizing and analyzing *SIM* simulation results. Type 5 is covered in Chapter 7

Type 1 input records activate routines that read the main *SIM* input DAT file and organize selected data. The 1REC routine simply lists *SIM* input records of user-selected types. The 1SUM record instructs *TABLES* to create water right summary tables organized in user-selected formats. A 1SRT 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 1CPT 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 6, 7, and 8 options described in the *Daily and Salinity Manuals* 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.

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 and also hydropower production associated with individual water rights. Monthly or annual tables of hydropower targets, hydropower production, and releases from all system reservoirs associated with system water rights with the *TABLES* 4HRR 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.

<u>DATA Record Transformation of Simulation Results Data</u>

The DATA record converts *SIM* or *SIMD* simulation results to other related datasets that can be read by the time series and frequency records described in the following sections of this chapter. All of the simulation results time series variables from the *SIM* output OUT or SIMD SUB output files listed in Table 5.1 can be read with a DATA record and manipulated to create other datasets consisting of daily or monthly quantities or annual totals, minima, or maxima covering a specified number of time periods defining a season of the year. The new dataset can be read and organized by time series records just like the original variables listed in Table 5.1. Time series record identifiers are listed in column 2 of Table 5.1. The DATA record also allows 2FRE and 2FRQ record frequency analyses to be performed for all of the variables listed in Table 5.1 and other adjusted datasets derived from the variables listed in Table 5.1.

The sole purpose of the DATA record is to transform *SIM* or *SIMD* simulation results to other time series variables of interest to be accessed as input by *TABLES* time series and/or frequency analysis record routines. Although the DATA record has broad general applicability, environmental instream flow studies based on daily *SIMD* simulation results provide a key motivation for its design. The *Daily Manual* describes the daily (type 6) equivalents of the *TABLES* time series records listed in Table 5.1 and the daily 6FRE and 6FRQ record versions of the monthly 2FRE and 2FRQ frequency analysis records. Determining annual exceedance probabilities for the minimum 7-day volume of naturalized or regulated stream flow is an example of combining the DATA and frequency records with *SIMD* daily simulation results.

The 35 *TABLES* time series record identifiers listed in Table 5.1 represent 31 monthly time series variables read directly from the *SIM* output OUT file and 4 other variables computed by combining simulation result variables. The variables are associated with either control points, water rights, or reservoirs. Several of the water right variables are also aggregated by control point or reservoir in the *SIM* simulation results. All of these variables have daily equivalents recorded in the *SIMD* output SUB file discussed in the *Daily Manual*. Examples 7.3 and 7.4 of the *Daily Manual* illustrate the use of the DATA record with daily data. The time series records with identifiers listed in the second column of Table 5.1 can be applied directly with all 35 variables without using a DATA record. 2FRE and 2FRQ record frequency analyses can be performed directly without a DATA record with six of the 35 variables. The *TABLES* routines activated by the DATA record work with any of the 35 variables and develop other transformed datasets that are not otherwise available to the time series and frequency records.

Any number of DATA records may be included in a *TABLES* input TIN file. Any number of time series and/or frequency records may use datasets created by each DATA record.

The DATA record performs the following tasks in the sequential order listed below.

<u>*Step 1*</u>: *SIM* monthly or *SIMD* daily simulation results are read from an OUT or SUB file. Only data that falls within the season (months) specified on the DATA record are read.

<u>*Step 2*</u>: The following equation with factors *XF* and *AF* from the DATA record, with defaults of *XF*=1.0 and *AF*=0.0, converts the original data series X1 to a new series X2.

$$X2 = (XF)(X1) + AF$$

<u>*Step 3*</u>: Optionally, either moving averages or moving totals of the quantities at the completion of step 2 in the current and preceding specified number of time steps (months for *SIM* or days for *SIMD*) may be computed.

<u>*Task 4*</u>: Optionally, the monthly or daily dataset at the completion of step 3 may be converted to an annual series consisting of either the total, minimum, or maximum for each year.

<u>*Task 5*</u>: The resulting annual data array and/or monthly (*SIM*) or daily (*SIMD*) data array are stored in memory for subsequent use by time series and/or frequency analysis records. Thus, the final product of a DATA record is either one or two datasets (annual and/or monthly/daily) stored in computer memory as arrays.

<u>*Task 6*</u>: An option allows the arrays to be written to the message file for general information.

Data are read and manipulated for only the months in the specified season, which may range from one to 12 months. The default season is the entire year (months 1-12). In creating an annual series, the year is always defined as months 1 through 12 which are typically though not necessarily January through December. The season specified on the DATA record may fall within a single year or may encompass parts of two years. For example, a 4-month long season defined as months 5 through 8 (May-October) falls totally within the year. A 4-month season defined as months 11 through 2 (November through February) is split between years.

The DATA options listed above as steps 2 and 3 are also options in the time series and frequency records. The computations are identical with either of the record types. The steps 2 and 3 options can be applied to the original simulation results by a DATA record and then to the resulting dataset by time series or frequency records. Moving totals are the summation of amounts for a specified number of time steps (months or days) that include the current and preceding time steps. Moving averages are moving totals summed over the specified number of time steps divided by the number of time steps.

Illustration of the DATA Record Using the Fundamentals Manual Example

The *TABLES* output TOU file reproduced as Table 5.8 is created from the *SIM* simulation results of the example presented in the *Fundamentals Manual*. The *TABLES* input TIN file consists of the following DATA record followed by two 2FRE records presenting frequency analysis results in two different formats.

```
DATA2REG   0   0   0   0   0   0   6   0   8
2FRE  11   0   0   2            0.005480
2FRE  11   0   0   1            0.005480
ENDF
```

The example consists of estimating the frequency (probability or likelihood) of the mean regulated flow during the summer months of June through August either exceeding or falling below various levels at eleven control points. The DATA record reads the monthly regulated flows at the 11 control points during the 696 months of the 1940-1997 simulation from the *SIM* output OUT file. The regulated flows in June, July, and August in each of the 58 years are summed to develop a 58-year annual series of 3-month regulated flow volumes in acre-feet.

Although performing a frequency analysis of flows in units of acre-feet is fine, the units are converted to cubic feet per second (cfs) in this example by applying the multiplier factor 0.005480 entered on the 2FRE record. This optional unit conversion factor is calculated as:

(acre-feet/92 days) (43,560 acre-feet/cubic foot) (day/86,400 seconds) = 0.005480

Thus, the frequency analysis is performed for the mean summer (June-August) regulated stream flow in units of cfs. The frequency analysis results are presented in Table 5.8.

The 75% exceedance frequency mean summer flow at control point PK is 276.99 cfs. Based on the 3-month June-July mean flow at PK equaling or exceeding 277 cfs during 75% of the 58 years of the simulation, the probability that the mean flow during any summer will be less than 277 cfs is estimated to be 25%. The median (50% exceedance frequency) mean flow during June through July is 760 cfs at control point PK and 882 cfs at control point Hemp.

Table 5.8
TABLES Output TOU File for DATA Record Example

VARIABLE 2REG IN DATA RECORD DATASET
DATA Record Parameters DR(1-10) 0 0 1 0 0 1 6 1 8 99

CP	PK	Whit	WacoL	WacoG	High	Belton	George	Grang	Camer	Bryan	Hemp
Mean	1064.00	1421.95	209.86	1988.84	2208.19	482.55	79.16	258.48	1069.48	3601.91	2897.01
Std Dev	1066.75	1347.09	269.63	1507.38	1729.61	453.28	108.49	294.47	1083.82	2739.15	3579.25
Minimum	0.00	0.00	0.00	73.57	17.05	0.00	0.00	0.00	4.97	3.90	165.75
99.5%	0.00	0.00	0.00	138.01	82.24	0.00	0.00	0.00	4.97	146.69	165.75
99%	0.00	0.00	0.00	202.45	147.42	0.00	0.00	0.00	4.97	289.48	165.75
98%	0.00	0.00	0.00	347.01	305.51	0.00	0.00	0.00	4.97	610.91	165.75
95%	0.00	0.00	0.00	618.05	644.33	0.00	0.00	0.00	4.97	1270.43	165.75
90%	0.00	82.08	0.00	718.18	780.71	1.18	0.00	1.04	43.25	1490.97	165.75
85%	66.71	261.77	0.00	815.87	849.72	35.90	0.00	3.17	63.64	1651.21	165.75
80%	132.66	399.06	0.00	888.98	904.86	52.64	0.00	6.98	169.22	1709.06	165.75
75%	276.99	599.05	0.00	986.78	973.72	62.97	0.29	24.27	295.35	1737.25	165.75
70%	458.97	680.28	1.65	1033.86	1064.62	108.36	0.68	52.93	373.57	1825.65	197.83
60%	622.64	844.80	46.73	1401.36	1425.35	206.35	3.03	76.94	598.64	1911.41	431.48
50%	759.86	1219.59	107.10	1544.47	1587.38	348.27	27.95	159.10	853.39	2160.28	882.19
40%	1050.76	1435.31	143.37	1755.62	1874.70	594.46	53.01	302.42	990.91	3372.74	2941.22
30%	1450.35	1597.52	310.47	2129.00	2662.31	794.03	84.14	386.51	1254.10	4456.94	4356.33
25%	1527.02	1771.73	396.46	2470.52	2808.75	875.57	131.30	403.52	1550.02	5270.70	4731.28
20%	1645.33	2154.05	447.03	3094.67	3680.72	925.60	205.78	430.44	1845.96	6116.38	5578.34
15%	1836.09	2629.88	551.58	3723.21	4096.70	1060.56	221.84	492.98	2195.83	6848.11	6908.87
10%	2758.59	3094.91	688.44	3891.32	4869.90	1249.25	257.24	636.15	2617.88	7700.67	8645.40
5%	3474.63	4472.02	816.20	5192.05	5803.72	1331.01	315.00	914.60	3703.36	9219.68	10998.34
2%	4785.12	6510.57	947.25	7249.09	8068.40	1450.27	392.47	1338.14	4759.87	12281.09	14026.07
1%	4876.21	6617.10	968.61	7264.36	8218.37	1450.98	401.44	1362.08	4879.57	12392.87	14136.72
0.5%	4876.21	6617.10	968.61	7264.36	8218.37	1450.98	401.44	1362.08	4879.57	12392.87	14136.72
Maximum	4876.21	6617.10	968.61	7264.36	8218.37	1450.98	401.44	1362.08	4879.57	12392.87	14136.72

VARIABLE 2REG IN DATA RECORD DATASET
DATA Record Parameters DR(1-10) 0 0 1 0 0 1 6 1 8 99

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF YEARS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	1064.0	1067.	0.0	0.0	0.0	0.0	0.0	277.0	623.	760.	1051.	1527.	2759.	4876.
Whit	1421.9	1347.	0.0	0.0	0.0	0.0	82.1	599.1	845.	1220.	1435.	1772.	3095.	6617.
WacoL	209.9	270.	0.0	0.0	0.0	0.0	0.0	0.0	47.	107.	143.	396.	688.	969.
WacoG	1988.8	1507.	73.6	202.5	347.0	618.0	718.2	986.8	1401.	1544.	1756.	2471.	3891.	7264.
High	2208.2	1730.	17.0	147.4	305.5	644.3	780.7	973.7	1425.	1587.	1875.	2809.	4870.	8218.
Belton	482.5	453.	0.0	0.0	0.0	0.0	1.2	63.0	206.	348.	594.	876.	1249.	1451.
George	79.2	108.	0.0	0.0	0.0	0.0	0.0	0.3	3.	28.	53.	131.	257.	401.
Grang	258.5	294.	0.0	0.0	0.0	0.0	1.0	24.3	77.	159.	302.	404.	636.	1362.
Camer	1069.5	1084.	5.0	5.0	5.0	5.0	43.2	295.3	599.	853.	991.	1550.	2618.	4880.
Bryan	3601.9	2739.	3.9	289.5	610.9	1270.4	1491.0	1737.3	1911.	2160.	3373.	5271.	7701.	12393.
Hemp	2897.0	3579.	165.8	165.8	165.8	165.8	165.8	165.8	431.	882.	2941.	4731.	8645.	14137.

Two alternative format options for 2FRE tables are compared in Table 5.8. As discussed later in this chapter, the 2FRE and 2FRQ records provide various alternative computational methods. The computation options are applied to datasets created with a DATA record in the same manner as to the original simulation results read directly from the *SIM* output file.

Another example of a derived variable consists of applying the DATA record moving total option with the default January through December season specified to develop an annual series of a variable defined as the minimum 3-month flow volume each year regardless of season. The DATA record provides flexibility in defining a variety of variables and developing annual, monthly, or daily datasets for these variables derived from simulation results.

<u>Time Series Tables and Tabulations</u>

The time series data from a *SIM* simulation results OUT file or DATA record array are written by *TABLES* to the tables in the *TABLES* output TOU file and/or as records to a DSS file as specified by input records with the identifiers listed in the second column of Table 5.1. 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 organized by *TABLES* in the following formats.

- A text file with the filename extension TOU has each time series organized as a separate table with annual rows and monthly columns with headings illustrated by Table 5.9. The variables in Table 5.1 are 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 5.10. Any of the 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 5.9
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	533.30	533.05	533.34	532.63	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 5.10
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.	287670.	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.	2183906.	291691.	1828.	187516.	1061780.	3537392.	3567118.
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.	235701.	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.

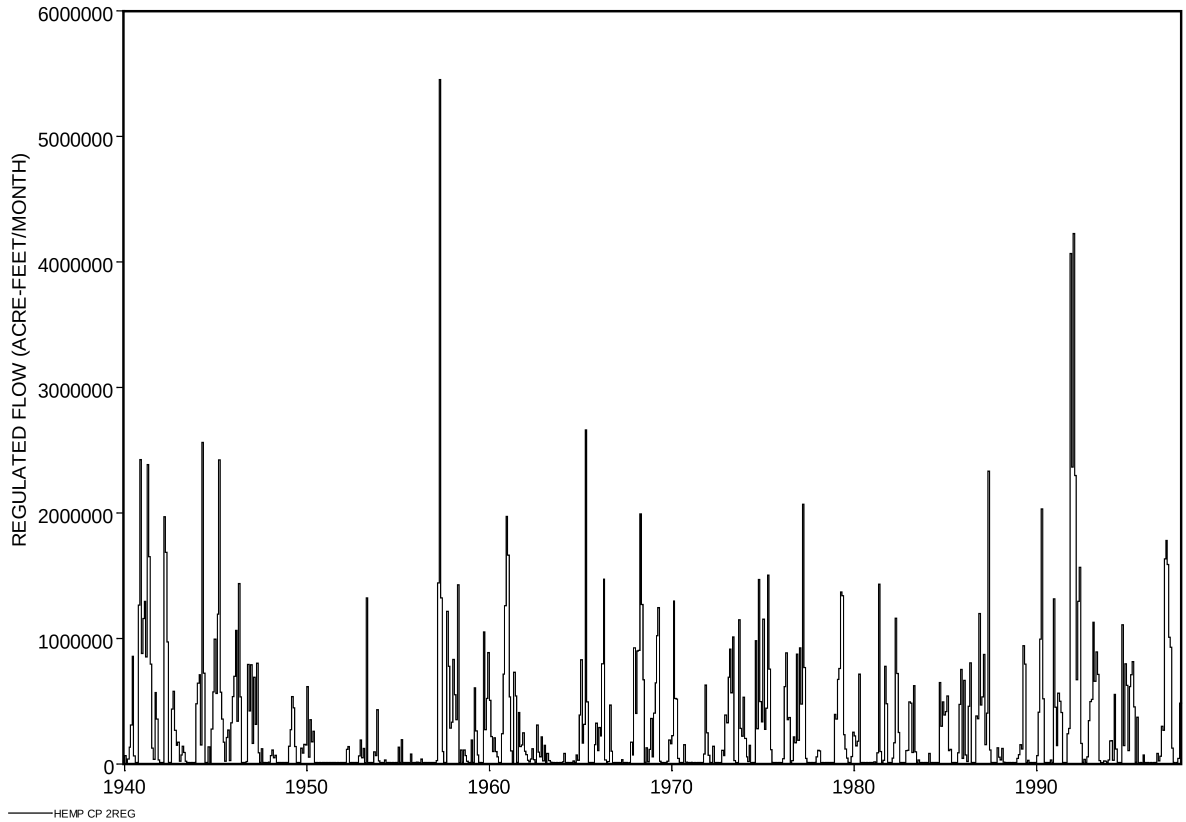

Figure 5.1 Time Series Plot Created with HEC-DSSVue

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. An optional auxiliary table of shortage metrics activated by 2REL record field 7 provides additional supplemental measures of water supply capabilities.

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.

$$R_V = \frac{v}{V} (100\%) \tag{5.1}$$

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:

$$R_P = \frac{n}{N} (100\%) \tag{5.2}$$

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 *Daily 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 5.11 and 5.12 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 5.11. 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 5.12 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 5.11 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 5.11
Reliability Table from the Example in the *Fundamentals Manual*

RELIABILITY SUMMARY FOR SELECTED WATER RIGHTS

NAME	TARGET DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS 100%	98%	95%	90%	75%	50%
WR-6	60000.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
WR-1	9800.0	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	32300.0	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 5.12
Hydropower Reliability Table from the Example in the *Fundamentals Manual*

RELIABILITY SUMMARY FOR SELECTED HYDROELECTRIC POWER PROJECTS

NAME	ENERGY TARGET	MEAN SHORTAGE	*RELIABILITY* PERIOD (%)	*RELIABILITY* AMOUNT (%)	PERCENTAGE OF MONTHS WITH ENERGY GENERATION EQUALING OR EXCEEDING PERCENTAGE OF TARGET 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS 100%	98%	95%	90%	75%	50%	1%
Whit	36000.0	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 5.11 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 5.12. 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 5.11 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.

Diversion Shortage Summary Metrics

An additional table with metrics summarizing failures to supply diversion requirements is created by the *2REL* record field 7 switch along with the standard reliability table. The shortage summary table is applicable to the results of conventional long-term simulations covered in this chapter or conditional reliability modeling (CRM) covered in Chapter 7. In conditional reliability modeling, the sequence length is an integer number of months defined by the parameter *CR1* on the *CR* record. For a conventional long-term simulation, the metrics are computed either by treating the conventional simulation as a single sequence with the length being the entire period-of-analysis or by treating each year (12 months from January through December) as a sequence. The supply failure metrics are defined as follows.

A shortage volume in a particular month of the simulation is the diversion target less the actual diversion as constrained by water availability. Shortages represent failures to fully meet water supply diversion requirements. A shortage period is defined as one or more consecutive months of a simulation during which a failure to meet the full diversion target occurs in each of the months.

The metrics are defined as follows in the order in which they are tabulated on the *2REL* record shortage summary table. Although any set of consistent units may be adopted in a *WRAP-SIM* simulation, acre-feet is used below to represent any volume unit.

Maximum Shortage − The maximum shortage in any month during the entire simulation.

Vulnerability − The average maximum shortage that occurred during each sequence in which a shortage occurred. In the case of a conventional long-term simulation, sequence length is defined on a January −December yearly basis.

Resiliency − The inverse of the mean of the average length of the shortage periods that occurred during each sequence, counting only those sequences for which shortages occurred.

Average Severity− the average sum of consecutive shortages that occurred during each sequence counting only those sequences during which shortages occurred.

Shortage Index:

$$\text{Shortage Index} = \frac{100}{\text{months}} \sum \left(\left(\frac{\text{annual or sequence shortage}}{\text{annual or sequence target}} \right)^2 \right)$$

Average Number of Failures per Sequence − average number of months of consecutive shortage that occurred during each sequence including those sequences during which no shortage occurred. In the case of a long-term simulation, sequence length is defined on a yearly basis from January to December.

Maximum Number of Consecutive Shortages − maximum number of consecutive months with shortages that occurred during the simulation.

The following example illustrates the above definitions. The diversion shortages occurring during three 12-month simulation sequences are tabulated below and the metrics defined above are computed assuming these are the only sequences in the simulation. Sequence 1 has two short periods (January−March and December). Sequence 2 also has two shortage periods (January−March and June−October). The third sequence has only one shortage period.

Seq	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Target (acre-feet)						
1	2,733	2,649	2,775	2,901	3,447	4,414	4,667	4,457	4,204	3,742	3,111	2,901
2	2,733	2,649	2,775	2,901	3,447	4,414	4,667	4,457	4,204	3,742	3,111	2,901
3	2,733	2,649	2,775	2,901	3,447	4,414	4,667	4,457	4,204	3,742	3,111	2,901
						Shortage (acre-feet)						
1	2,250	991	1,070	0	0	0	0	0	0	0	0	2,372
2	2,505	2,404	2,775	0	0	2,478	4,667	4,457	4,204	3,742	0	0
3	2,733	1,641	0	0	0	0	0	0	0	0	0	0

maximum shortage = 4,667 acre-feet

$$\text{vulnerability} = \frac{2{,}372 + 4{,}667 + 2{,}733}{3} = 3{,}257 \text{ acre-feet}$$

$$\text{resiliency} = \frac{1}{\frac{3+1}{2} + \frac{3+5}{2} + \frac{2}{1}} = 0.375 \text{ months}$$

average severity =

$$\frac{\frac{2{,}250+991+1{,}070+2{,}372}{2} + \frac{2{,}505+2{,}404+2{,}775+2{,}478+4{,}667+4{,}457+4{,}204+3{,}742}{2} + \frac{2{,}733+1{,}641}{1}}{3}$$

= 7,110.5 acre-feet

$$\text{shortage index} = \frac{100}{36 \text{ months}} \sum\left(\left(\frac{\text{annual or sequence shortage}}{\text{annual or sequence target}}\right)^2\right) = 15.22 \text{ months}^{-1}$$

$$\text{average number of failures per sequence} = \frac{2 + 2 + 1}{3} = 1.67$$

maximum number of consecutive months with shortages = 5 months

<u>Flow and Storage Frequency Analyses</u>

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
- any simulation results variables or modifications thereof from a DATA record

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

Frequencies may be based on considering all months or alternatively be developed for a specified month of the year such as May or August. Optionally, frequency analysis may be applied to moving averages or moving accumulative totals of the data computed for a user-specified number of months. The data may be adjusted by a multiplier factor, which may be a unit conversion factor or serve other purposes. The data may be added or subtracted from a constant. For example, the time series data for a frequency analysis of reservoir draw-downs is developed by subtracting water surface elevations from the 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 5.13 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 illustrated by Table 5.8 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 5.14. 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 5.13
2FRE Frequency Table from the Example in the *Fundamentals Manual*

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	43379.9	119616.	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.	10233.	38502.	78247.	189804.	2970632.
WacoL	21636.4	51914.	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.	1194.	19413.	92619.	524452.
George	3004.7	7642.	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.	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 5.14
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.

$$\text{Exceedance Frequency} = \frac{n}{N}\ (100\%) \tag{5.3}$$

The *Fundamentals Manual* example is based on a 58-year 1940−1997 hydrologic period-of-analysis. N is 696 months for Table 5.13 with all months considered in the frequency analysis. N is 58 months in Table 5.14 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 5.13, *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 5.14) was equaled or exceeded.

Table 5.13 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.

$$X = \overline{X} + z\,S \tag{5.4}$$

$$\log X = \overline{\log X} + z\,S_{\log X} \tag{5.5}$$

The frequency factor (z) is derived from a normal probability table. $\overline{X}$ 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 $\overline{X}$ 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.

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \tag{5.6}$$

$$S = \left[\frac{1}{n-1}\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2\right]^{0.5} \tag{5.7}$$

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 5.15 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 5.15
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		

<u>Choice of Alternative Frequency Method</u>

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 Chapter 7. The random variable is defined differently in CRM versus conventional simulations. The log-normal or normal distribution options perhaps may be more relevant for certain 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

$$\text{storage content as percentage of capacity} = \frac{S - C_2}{C_1 - C_2}(100\%) \tag{5.8}$$

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 5.16 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.

$$\text{drawdown as percentage of capacity} = 100\% - \frac{S - C_2}{C_1 - C_2}(100\%) \qquad (5.9)$$

Table 5.16
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 5.17, 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.

Table 5.17
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.

Alternatively, the storage-reliability table illustrated by Table 5.18 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 5.18
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 5.19 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.

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.

Table 5.19
Summary Table for a Control Point

ANNUAL SUMMARY TABLE FOR CONTROL POINT WacoL

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)
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	55675.4	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

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.

sum of all inflows − sum of all outflows = 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 5.20 shows the first 24 months of a water budget table for the Waco Lake control point. The entire tabulation is 696 months long. Table 5.21 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 5.22 and 5.23, respectively. The variable names used in the Fortran code are adopted in Tables 5.22 and 5.23 and the following discussion.

Table 5.20
Beginning of Control Point Water Budget Tabulation

YEAR	M	CPID	NAT(CP)	CLC(CP)	CL(CP)	FNAT	FREG	RET(CP)	CINF	FCLC	FCL	REG(CP)	DIV	FOTH	EVAP(CP)	BSTO(CP)	STO(CP)	XSTO	XSUM
1940	1	WacoL	1166.	0.	0.	1166.	0.	0.	0.	0.	0.	0.	5252.	0.	869.	192100.	187145.	-4955.	-4955.
1940	2	WacoL	1315.	0.	0.	1315.	0.	0.	0.	0.	0.	0.	5090.	0.	56.	187145.	183313.	-3831.	-3831.
1940	3	WacoL	1182.	0.	0.	1182.	0.	0.	0.	0.	0.	0.	5494.	0.	2661.	183313.	176339.	-6974.	-6974.
1940	4	WacoL	36755.	0.	0.	36755.	0.	0.	0.	0.	0.	15680.	5818.	0.	-503.	176339.	192100.	15761.	15761.
1940	5	WacoL	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	6868.	0.	2959.	192100.	182273.	-9827.	-9827.
1940	6	WacoL	61991.	0.	0.	61991.	0.	0.	0.	0.	0.	45625.	7514.	0.	-975.	182273.	192100.	9827.	9827.
1940	7	WacoL	41936.	0.	0.	41936.	0.	0.	0.	0.	0.	28529.	9534.	0.	3872.	192100.	192100.	0.	0.
1940	8	WacoL	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9211.	0.	5321.	192100.	177568.	-14532.	-14532.
1940	9	WacoL	2999.	0.	0.	2999.	0.	0.	0.	0.	0.	0.	7676.	0.	5260.	177568.	167631.	-9937.	-9937.
1940	10	WacoL	2477.	0.	0.	2477.	0.	0.	0.	0.	0.	0.	7030.	0.	2563.	167631.	160515.	-7116.	-7116.
1940	11	WacoL	93211.	0.	0.	93211.	0.	0.	0.	0.	0.	59268.	5737.	0.	-3378.	160515.	192100.	31585.	31585.
1940	12	WacoL	128574.	0.	0.	128574.	0.	0.	0.	0.	0.	123662.	5575.	0.	-663.	192100.	192100.	0.	0.
1941	1	WacoL	45901.	0.	0.	45901.	0.	0.	0.	0.	0.	39855.	5252.	0.	794.	192100.	192100.	0.	0.
1941	2	WacoL	129987.	0.	0.	129987.	0.	0.	0.	0.	0.	125764.	5090.	0.	-868.	192100.	192100.	0.	0.
1941	3	WacoL	94948.	0.	0.	94948.	0.	0.	0.	0.	0.	89462.	5494.	0.	-8.	192100.	192100.	0.	0.
1941	4	WacoL	133705.	0.	0.	133705.	0.	0.	0.	0.	0.	128068.	5818.	0.	-180.	192100.	192100.	0.	0.
1941	5	WacoL	174843.	0.	0.	174843.	0.	0.	0.	0.	0.	167566.	6868.	0.	409.	192100.	192100.	0.	0.
1941	6	WacoL	76423.	0.	0.	76423.	0.	0.	0.	0.	0.	68016.	7514.	0.	892.	192100.	192100.	0.	0.
1941	7	WacoL	61285.	0.	0.	61285.	0.	0.	0.	0.	0.	47837.	9534.	0.	3913.	192100.	192100.	0.	0.
1941	8	WacoL	46901.	0.	0.	46901.	0.	0.	0.	0.	0.	32704.	9211.	0.	4986.	192100.	192100.	0.	0.
1941	9	WacoL	5494.	0.	0.	5494.	0.	0.	0.	0.	0.	0.	7676.	0.	4802.	192100.	185116.	-6984.	-6984.
1941	10	WacoL	1926.	0.	0.	1926.	0.	0.	0.	0.	0.	0.	7030.	0.	-72.	185116.	180084.	-5032.	-5032.
1941	11	WacoL	7916.	0.	0.	7916.	0.	0.	0.	0.	0.	0.	5737.	0.	1955.	180084.	180308.	224.	224.
1941	12	WacoL	6814.	0.	0.	6814.	0.	0.	0.	0.	0.	0.	5575.	0.	1120.	180308.	180427.	119.	119.

Table 5.21
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 5.22
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
		Monthly Volumes Used in Intermediate Computations
4	NAT(cp)	naturalized flow from *SIM* output file
5	CLC(cp)	downstream channel loss credits from *SIM* output file
6	CL(cp)	downstream channel losses from *SIM* output file
		Monthly Control Point Inflows in Volume Budget
7	FNAT	computed incremental naturalized flows
8	FREG	computed regulated flows entering control point
9	RET(cp)	return flows from *SIM* output file
10	CINF(cp,m)	*CI* record inflows from *SIM* 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
		Monthly Control Point Outflows in Volume Budget
14	REG(cp)	regulated flows leaving control pt from *SIM* output file
15	DIV	diversion = target – shortage from *SIM* 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 *SIM* output file
		Reservoir Storage at Beginning and End of Month
18	BSTO(cp)	beginning-of-month storage
19	STO(cp)	end-of-month storage from *SIM* output file
		Water Budget
		XSTO = XSUM
20	XSTO	storage change = (19) – (18)
21	XSUM	inflows – outflows = (13) – (14) – (15) – (16) – (17)

Table 5.23
Summary Water Budget for the Entire River Basin(s)
for the Specified Period-of-Analysis

Description of Volume Quantity	Variable
Incremental naturalized flows	Σ FNAT
Return flows	Σ RET(cp)
CI record constant inflows	Σ CINF(cp,m)
Channel loss credits	Σ FCLC
Channel losses	Σ FCL
Regulated flows leaving river basin outlet	Σ REG(cp)
Water supply diversions	Σ DIV
Other releases for hydropower and instream flow	Σ FOTH
Net reservoir evaporation	Σ EVAP(cp)
Summation of inflows minus outflows = ΣFNAT+ΣRET(cp)+ ΣCINF(cp,m)+ΣFCLC−ΣFCL−ΣREG(cp)−ΣDIV−ΣFOTH−ΣEVAP(cp)	
Beginning-of-computations reservoir storage	Σ BSTO(cp)
End-of-computations reservoir storage	Σ STO(cp)
Change in storage = Σ STO(cp) − Σ BSTO(cp)	
Volume balance difference = summation of inflows minus outflows − change in storage	
Negative inflows to control point	Σ FINNEG
Negative incremental naturalized flows	Σ FNAT if < 0
Naturalized flows at river basin outlet(s)	Σ NAT(cp)

XSTO and XSUM in Table 5.22 should have the same values. The monthly volumes included in the control point water budget table are related as follows.

$$\text{storage change} = \Sigma \text{ inflows} - \Sigma \text{ outflows} \tag{5.10}$$

$$\begin{aligned}\text{STO(cp)} - \text{BSTO(cp)} &= \text{FNAT} + \text{FREG} + \text{RET(cp)} + \text{CINF(cp,m)} \\ &+ \text{FCLC} - \text{FCL} - \text{REG(cp)} - \text{DIV(cp)} - \text{FOTH} - \text{EVAP(cp)}\end{aligned} \tag{5.11}$$

Quantities are tabulated both as total period-of-analysis volumes and mean annual volumes in the 2BUD record water budget table providing totals for the entire river basin system for the specified period-of-analysis. The sum for all months of the incremental naturalized flow volumes (FNAT) at all control points represent flows entering the river system. Regulated flow volumes (REG(cp)) at the river basin outlet or multiple outlets, as defined by *SIM CP* records, 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.

$$\text{change in storage volume} = \Sigma \text{ inflow volume} - \Sigma \text{ outflow volume} \tag{5.12}$$

$$\begin{aligned}\Sigma \text{ inflow volume} - \Sigma \text{ outflow volume} = \Sigma\text{FNAT} + \Sigma\text{RET(cp)} + \Sigma\text{CINF(cp,m)} \\ + \Sigma\text{FCLC} - \Sigma\text{FCL} - \Sigma\text{REG(cp)} - \Sigma\text{DIV(cp)} - \Sigma\text{FOTH} - \Sigma\text{EVAP(cp)}\end{aligned} \tag{5.13}$$

$$\text{change in storage volume} = \Sigma \text{ STO(cp)} - \Sigma \text{ BPSTO(cp)} \tag{5.14}$$

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.

$$\begin{aligned}\text{volume balance difference} = \\ [\Sigma \text{ inflow volume} - \Sigma \text{ outflow volume}] - [\Sigma \text{ STO(cp)} - \Sigma \text{ BPSTO(cp)}]\end{aligned} \tag{5.15}$$

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 ΣFNAT, which is the first entry in the table.

<u>Other Reservoir Releases or Other Flows</u>

The other flow volume (FOTH) in Eq. 5.13 and Tables 5.22 and 5.23 is computed as follows.

$$\text{FIN2} = \text{flow in} = \text{flow out} + \text{storage change} \tag{5.16}$$

$$\text{FIN2} = \text{REG(cp)} + \text{DIV} + \text{EVAP(cp)} + \text{STO(cp)} - \text{BSTO(cp)} \tag{5.17}$$

$$FOTH = FIN2 – FIN \quad (5.18)$$

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
ADDITIONAL AUXILIARY MODELING FEATURES

The preceding Chapter 5 discusses *SIM* simulation results recorded in the OUT file and organized and analyzed with *TABLES*. The following Chapter 7 covers the conditional reliability modeling (CRM) variation of the *SIM* and *TABLES* modeling system where the OUT file is replaced by a CRM file. The present Chapter 6 covers *SIM* simulation results stored in other supplemental output files and associated modeling and analyses techniques. 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* and *TABLES*.

- 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.

SIM Output Files

SIM input and output files are explained in Chapter 2 of the *Users Manual*. *SIM* output files are also listed in Table 6.1 and described here in this chapter. The various types of *SIM* output files are referenced by their filename extensions which are tabulated in the first column of Table 6.1. This chapter discusses the *SIM* simulation results provided in the different files.

The main *SIM* simulation results consists of time series of variables defined in Chapter 5 stored in either an OUT file or CRM file. *SIM* creates either an OUT or CRM file but not both. The OUT file stores the results of a conventional long-term *SIM* simulation. The CRM file stores the results of the multiple shorter simulations generated when *SIM* is executed in CRM mode.

The OUT, CRM, ZZZ, HRR, and BES files are text files containing *SIM* simulation results that can be read, reorganized, and analyzed using program *TABLES*. The simulation results recorded in these text files can be read directly with any editor as well as reorganized and analyzed using *TABLES*. The text files can be examined using essentially any editor such as Microsoft WordPad. The BES file is designed to be both written by *SIM* and read by *SIM*.

Alternatively, the OUT or CRM 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 MSS, SOU, and YRO files are designed to be read with any editor but are not read by *TABLES*.

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. With the exception of the either/or OUT/CRM file, 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	Reference Manual Chapter
MSS	automatic	trace, error, and warning messages	Chapter 8
OUT	default	main simulation results read by *TABLES*	Chapter 5
SOU	*OF* record	main simulation results table	Chapter 5
DSS	*OF* record	main simulation results read by *HEC-DSSVue*	Chapter 5
YRO	*FY* record	yield-reliability table including firm yield	Chapter 6
ZZZ	*ZZ* record	priority sequence flow availability table	Chapter 6
BES	*JO* record	beginning and ending storage	Chapter 6
BRS	*JO* record	beginning reservoir storage	Chapter 6
HRR	*JO* record	hydropower and reservoir system releases	Chapter 6
CRM	*CR* record	results for conditional reliability modeling	Chapter 7

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 8 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 *Hydrology Manual*.

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.

The *SIM* output files *OF* input record allows selection of one of two alternative sets of simulation results variables to include in the SOU and/or DSS output files, the default abbreviated set of variables listed in Table 6.2 or the complete set listed in Table 6.3. The simulation results variables, with three-character identifiers listed in Tables 5.1 and 6.3, are defined in Chapter 5. The variables listed in Table 6.2 comprise an abbreviated subset of the variables listed in Table 6.3.

Table 6.2
Default Abbreviated Set of Variables in SOU and DSS Files

Control Point Variables	Water Right Variables	Reservoir Variables
NAT naturalized stream flow	TAR diversion or energy target	STO reservoir storage volume
REG regulated stream flow	SHT diversion shortage	EVA evaporation-precip volume
UNA unappropriated stream flow	DIV diversion or energy amount	EPD evaporation-precip depth
STO reservoir storage volume	STO reservoir storage volume	WSE water surface elevation
TAR diversion target	DEP stream flow depletion	
SHT diversion shortage	IFT instream flow target	
	IFS instream flow shortage	

Table 6.3
Complete Set of Variables in OUT, SOU, and DSS Files

Control Point Variables	Water Right Variables	Reservoir/Hydropower Variables
NAT naturalized stream flow	STO reservoir storage volume	STO reservoir storage volume
REG regulated stream flow	EVA evaporation-precip volume	EVA evaporation-precip volume
UNA unappropriated stream flow	DEP stream flow depletion	HPS shortage/secondary energy
CLC channel loss credits	TAR diversion or energy target	HPE energy generated
CLO channel losses	SHT diversion shortage	RID inflows from depletions
URR upstream reservoir releases	DIV diversion or energy amount	RIR inflows from releases
CPI control point inflows	ASF available stream flow	RAH releases accessible to hydro
STO reservoir storage volume	ROR secondary reservoir release	RNA releases not accessible
TAR diversion target	RFL return flow or IFT instream flow target	EPD evaporation-precip depth
SHT diversion shortage	XAV available increase or IFT instream flow shortage	WSE water surface elevation
EVA reservoir net evaporation	FSV IF right *FS* record flow	RSC reservoir storage capacity
DEP stream flow depletions	FSC IF right *FS* record count	

The SOU file organization is illustrated by the example in Table 6.4, which contains the abbreviated set of variables listed in Table 6.2. Table 6.4 includes only the beginning of the lengthy SOU file. A SOU file contains tables for each individual control point, followed by tables for each water right, followed by tables for each reservoir. The mechanism for selecting the control points, water rights, and reservoirs to be included in the OUT, SOU, and/or DSS output files is described in Chapter 2 of the *Users Manual*. Table 6.4 shows only the first several months of simulation results for the first control point. The 3-character headings denoting variables are defined in Chapter 5.

Table 6.4
Beginning of SOU File for the *Fundamentals Manual* Example

Control point identifier: PK

YEAR	MT	NAT	REG	UNA	STO	TAR	SHT
1940	1	10094.00	66120.23	0.00	497885.97	13893.514	0.000
1940	2	10172.00	0.00	0.00	491928.12	15346.859	0.000
1940	3	836.00	0.00	0.00	468528.19	17850.770	0.000
1940	4	16772.00	0.00	0.00	461625.97	21081.352	0.000
1940	5	114403.00	0.00	0.00	548220.31	23909.152	0.000
1940	6	289797.00	239386.02	239386.02	570240.00	26687.953	0.000
1940	7	45691.00	3185.21	3185.21	570240.00	28896.881	0.000
1940	8	242432.00	206742.31	74320.56	570240.00	27139.242	0.000
1940	9	54126.00	93567.66	0.00	496344.56	24498.135	0.000
1940	10	3317.00	0.00	0.00	470936.38	21228.352	0.000
1940	11	79433.00	0.00	0.00	534165.50	18371.150	0.000
1940	12	49363.00	0.00	0.00	567853.44	15896.641	0.000
1941	1	9910.00	0.00	0.00	561699.88	13893.514	0.000
1941	2	75951.00	54675.66	54675.66	570240.00	15346.859	0.000
1941	3	64391.00	43619.38	43619.38	570240.00	17850.770	0.000
1941	4	201160.00	179899.16	179899.16	570240.00	21081.352	0.000
1941	5	1267722.00	1244269.75	1244269.75	570240.00	23909.152	0.000
1941	6	627107.00	599129.94	599129.94	570240.00	26687.953	0.000
1941	7	140733.00	103367.27	103367.27	570240.00	28896.881	0.000
1941	8	116128.00	83440.77	83440.77	570240.00	27139.242	0.000
1941	9	103454.00	71041.81	33471.57	570240.00	24498.135	0.000
1941	10	758197.00	740215.88	634342.75	570240.00	21228.352	0.000
1941	11	137798.00	114270.48	114270.48	570240.00	18371.150	0.000
1941	12	43317.00	24727.95	24727.95	570240.00	15896.641	0.000
1942	1	26025.00	12151.72	0.00	566622.56	13893.514	0.000
1942	2	13531.00	0.00	0.00	560748.06	15346.859	0.000
1942	3	14131.00	14162.09	0.00	536867.00	17850.770	0.000
1942	4	468326.00	419911.50	419911.50	570240.00	21081.352	0.000
1942	5	139111.00	111171.39	111171.39	570240.00	23909.152	0.000
1942	6	151003.00	118424.38	118424.38	570240.00	26687.953	0.000
1942	7	15609.00	0.00	0.00	544145.00	28896.881	0.000

The SOU and DSS files contain *SIM* simulation results for one of the two alternative sets of variables listed in Tables 6.2 and 6.3 for all months of the simulation. The OUT file contains the complete set of variables listed in Tables 5.1 and 6.3. Any number of control points, water rights, and/or reservoir/hydropower projects may be selected for inclusion in the output files. Program *TABLES* reads an OUT file but not a SOU or DSS file. HEC-DSSVue reads only a DSS file.

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. Simulation results are normally not recorded in an OUT file if a YRO file is created.

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* 2ZZZ and 2ZZF 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* described in the salinity Manual and the *TABLES* CRM routine described in Chapter 7 of this 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 a 4HRR input record 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 7. The CRM file activated by a *CR* record. 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.

NotePad++

Notepad++ is an enhanced text editor that is similar to Microsoft Notepad and Wordpad but provides additional features which are useful in creating and editing WRAP input data files and viewing output files. Notepad++ Portable is a full-featured Notepad++ text editor packaged as a portable app for convenience in application. Notepad++ is available free-of-charge at:

http://notepad-plus-plus.org

http://portableapps.com/apps/development/notepadpp_portable

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 is 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 2009) 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 (CRWR) 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 and CRWR as an executable setup file along with a users manual (CRWR 2007).

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 6.5 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 6.5 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 6.5
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 6.6, 6.7, and 6.8. The ZZZ file partially reproduced as Table 6.6 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 6.6
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   ---------
                                   |Reservoir Regulated Available|Reservoir Regulated Available
Year M  Water Right        M   WR  | Releases    Flow      Flow  | Releases    Flow      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 6.6. 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 6.6, 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 reminder 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 6.6 and creates the tables reproduced as Tables 6.7 and 6.8 which are stored in the *TABLES* output TOU file. Only tables for control point Grang are shown in Tables 6.7 and 6.8.

```
4ZZZ   1   0   0   3   2   WR-15
IDEN  George   Grang
4ZZF   3   0  -2
```

Table 6.7
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	0.0	10438.8	7636.2	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 6.8

4ZZF Frequency Analysis Table for the Example

FREQUENCY TABLE FOR AVAILABLE FLOWS AT CONTROL POINT Grang

WR	WATER RIGHT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
				PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
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 6.7 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 6.6 and 6.8 meaning 21 other more senior rights are found in the *SIM* input. The flows in Table 6.7 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 6.6 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 6.8 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 or 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. However, the reservoir storage table may also be useful for general information.

General Framework for WRAP Applications

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 in conjunction with the Texas WAM System use the modeling capabilities described in Chapters 2, 3, 4, and 8 of this *Reference Manual* and all of the chapters of the companion *Users Manual*. The preceding Chapter 5 focuses on the time series variables of *SIM* simulation results stored in the default OUT or alternative SOU or 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 auxiliary *SIM* output files.

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 6 of this *Reference Manual* are in routine use.

However, the additional more recently developed modeling capabilities provided by the other WRAP programs and documented by the *Daily, Hydrology, and Salinity Manuals and Chapter 7 of this Reference Manual* have not yet as of August 2012 reached the stage of being routinely applied but are currently beginning to be 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. The original 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 modeling system has since then continued to be extensively applied in the preparation and evaluation of water right permit applications, regional and statewide planning studies, and other water management activities. The WRAP programs have been greatly expanded and improved in response to challenges encountered and experience gained in modeling the diverse individual river basins of the state.

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.

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 WRAP program *HYD* described in the *Hydrology Manual* is designed to assist in developing and updating 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 originally developed during 1998-2001 prior to completion of the initial program *HYD*. Microsoft Excel was used for most of the computational tasks that have since been incorporated into *HYD*. The original *HYD* developed during 1998-2000 was significantly expanded during 2007-2008 and 2011-2012. The *Hydrology Manual* documents recently developed methodologies for more efficiently extending the hydrologic period-of-analysis of the existing datasets to the present. Condensed datasets with a reduced number of control points, water rights, and reservoirs can also be developed with the naturalized flows being replaced with flows reflecting specified water use and infrastructure.

Development of the WRAP program *SALT* and associated salinity-related routines in *TABLES* described in the *Salinity Manual* was motivated by natural salt pollution in the upper watersheds of several river basins in Texas and neighboring states that severely constrains water supply capabilities of major river/reservoir systems. A salinity simulation begins with a regular *SIM* simulation. *SALT* reads water quantity data from the *SIM* 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 as concentration and load time series and frequency tables, supply reliability tables, and summary tables. Salt loads and concentrations can be stored in a DSS file for plotting with HEC-DSSVue. Wurbs and Lee (2009, 2011) describe a WRAP salinity simulation study of the Brazos River Basin.

The expanded capabilities documented in the *Daily Manual* represent a major new direction in WRAP modeling. A daily simulation is much more complex than a monthly simulation due to the need to incorporate flow forecasting and routing. Although the greater detail provided by a daily computational time step can also be useful in modeling water supply and hydropower operations, environmental flows and flood control operations are the primary motivations for the daily WRAP modeling system. The environmental instream flow modeling and analysis capabilities described in this monthly *Reference Manual* can be performed significantly more accurately with a daily time step. The daily *SIMD* also includes features for modeling high pulse environmental flow requirements that are not possible with the monthly *SIM*. *SIMD* also provides comprehensive capabilities for simulating reservoir flood control operations. Any number of reservoirs with flood control pools can be operated either individually or as multiple-reservoir systems to control flooding at any number of downstream control points. Uncontrolled surcharge reservoir releases can also be included in the simulation. Wurbs et al. (2012) report a daily WRAP case study of the Brazos River Basin.

The WRAP modeling capabilities presented in Chapters 1 through 6 of this *Reference Manual* deal with a long term simulation, with typically a hydrologic period-of-analysis of at least 50 years, designed to support planning studies and evaluation of water right permit applications. The following Chapter 7 covers conditional reliability modeling (CRM) designed for evaluating stream flow and reservoir storage conditions and water supply capabilities over a short time frame ranging from one month to several months to perhaps one or two years. *TABLES* develops CRM frequency and reliability relationships from *SIM* or *SIMD* monthly simulation results. Although CRM is based on monthly simulation results, a *SIMD* simulation can be performed at a daily computational time step with the simulation results aggregated to monthly quantities.

CHAPTER 7
SHORT-TERM CONDITIONAL RELIABILITY MODELING

Conditional reliability modeling (CRM) consists of developing short-term reliability and frequency estimates conditioned on preceding reservoir storage. The terms *conditional* and *short-term* are used interchangeably. CRM is based on dividing a long hydrologic period-of-analysis into many shorter simulation sequences. The simulation is repeated for each hydrologic sequence with the same initial storage condition. Water supply and hydropower reliability indices and flow and storage frequency relationships are developed from the simulation results. The programs *SIM* or *SIMD* perform the multiple short-term simulations with the specified starting reservoir storage contents. Routines in the program *TABLES* read the simulation results and perform reliability and frequency analyses.

A separate initial CRM version of *WRAP* described by Salazar (2002) and Salazar and Wurbs (2004) was subsequently redesigned with the newer computational methods integrated directly into the generic *SIM* and *TABLES*. Wurbs, Hoffpauir, and Schnier (2012) and Wurbs, Schnier, and Olmos (2012) illustrate the CRM methodologies with a case study application.

Conventional Versus Conditional Reliability Modeling

WRAP was originally designed for long-term planning studies and preparation and evaluation of water right permit applications. Conditional reliability modeling (CRM) features expand WRAP capabilities to support short-term drought management and operational planning activities in which consideration of preceding reservoir storage levels is important. Using CRM, the likelihood of meeting reservoir storage, water supply diversion, instream flow, and hydroelectric power generation targets during the next month, next several months, next year, or next several years is assessed as a function of the amount of water currently in storage along with all the other information otherwise reflected in WRAP. Water supply reliabilities and storage and flow frequencies are conditioned on preceding storage contents.

A WRAP simulation study, either conventional or CRM, involves assessing capabilities for meeting specified water management and use requirements, with river basin hydrology being represented by historical naturalized stream flow sequences and net reservoir evaporation less precipitation rates. For example, based on the availability of historical flow records, a 1940-2009 period-of-analysis may be adopted to represent the hydrologic characteristics of a river basin. In a conventional WRAP simulation, the model allocates water to meet specified water management/use requirements during each sequential month of a single 840-month hydrologic sequence starting in January 1940. Initial reservoir storage contents are specified corresponding to the beginning of January 1940 in the hydrologic period-of-analysis. In CRM, the long sequences of naturalized flows and net evaporation rates are divided into many short sequences. For example, the 1940-2009 hydrologic period-of-analysis may be divided into 70 annual simulation sequences starting and ending in specified months. The system is simulated 70 times with 70 different naturalized stream flow and net evaporation sequences, with each simulation sequence having the same starting reservoir storage contents. The reliability indices and frequency relationships developed from the CRM simulation results have the same format as with the conventional WRAP modeling approach but are interpreted differently.

With the conventional WRAP modeling approach, reliability parameters provide a measure of the likelihood of meeting water supply, environmental instream flow, and hydroelectric power production requirements during any randomly selected future month or year without regard to the amount of water actually contained in reservoir storage today. This type of modeling is designed for long-term planning studies and preparation and evaluation of water right permit applications. The purpose of the CRM features is to expand WRAP capabilities to include evaluation of reliabilities in meeting water needs during the next relatively short periods of time typically ranging from a month to a year, perhaps longer, which is highly dependent on the amount of water currently in storage. Reliabilities and frequencies are conditioned upon preceding storage. The likelihood of a reservoir being full or almost full three months from now is significantly higher if the reservoir is almost full now than if it is almost empty now.

CRM is a decision-support tool for water management during drought, developing river/reservoir system operating policies, administration of water right systems and water supply contracts, and related applications. CRM may be applied by a regulatory agency in deciding upon water use curtailment actions during drought. Reservoir management agencies may use the model to develop permanent operating rules or to develop operating plans for the next year or season in ongoing operational planning activities. Commitments to water users may be set annually or seasonally depending on the amount of water in storage at the beginning of the season or year. For proposed reservoir construction projects, CRM may be used to evaluate impacts on the other water users in the river basin during the initial impoundment period.

Computer Programs, Data Files, and Input Records

Conditional reliability modeling capabilities are included in *SIM*, *SIMD*, and *TABLES*. The multiple short-term simulations are performed within either *SIM* or *SIMD*. The *SIMD* version provides the option of performing the simulation computations using a daily time interval and then aggregating the daily results to monthly totals. Otherwise, a CRM analysis is performed in the same manner with either *SIM* or *SIMD*. *TABLES* reads the monthly simulation results from a *SIM* or *SIMD* output file and creates reliability and frequency tables.

SIM or *SIMD* is switched to the CRM mode by entering a conditional reliability *CR* record in the input file. The *CR* record is the only *SIM/SIMD* input record that is used solely for CRM. The *CR* record sets the time parameters that control the subdivision of the hydrologic period-of-analysis into multiple short-term sequences. Without a *CR* record, the model performs a conventional single hydrologic period-of-analysis simulation. Simulation results are stored in the main *SIM/SIMD* output file with filename extension OUT or CRM which is read by *TABLES*.

Instructions for preparing CRM-related input records for *TABLES* are provided in the *Users Manual*. *TABLES* provides alternative approaches for assigning probabilities to each of the CRM hydrologic sequences. With the default equal-weight option, the *TABLES* input records are the same as with a conventional non-CRM analysis, with the exception of adding a *5CRM* record. The *5CRM* record, which has no actual input data, is used to switch *TABLES* from the conventional to CRM mode of analysis. A set of optional *5CR1* and *5CR2* records activates options that assign probabilities to each hydrologic sequence, which may vary between sequences, based on either a storage-flow-frequency (SFF) or flow-frequency (FF) relationship.

The correlation coefficient *5COR* record provides auxiliary capabilities for investigating the correlation between naturalized flow volume and preceding reservoir storage content.

The results of *SIM/SIMD* conventional long-term and CRM short-term simulations are recorded in OUT and CRM files, respectively. The OUT and CRM output files contain the same type of simulation results data in the same format. However, the CRM file created by *SIM* or *SIMD* reflects repetition of the same user-specified initial storage conditions at the beginning of each of the multiple user-defined hydrologic sequences.

The *TABLES 5CR1* record optional creation of a storage-flow-frequency (SFF) array uses an OUT output file from a conventional long-term *SIM/SIMD* simulation. The *5CR2* record uses a CRM output file from a CRM application of *SIM* or *SIMD*. Thus, output files from two separate executions of *SIM/SIMD* may be read by *TABLES* in performing CRM computations activated by *5CR1* and *5CR2* record options. The *5CR1* and *5CR2* records contain options that allow creation of an extra file, with filename extension SFF, for a storage-flow-frequency (SFF) array. However, the SFF array may also be developed and applied without reading and writing to a SFF file. Options also allow a beginning-of-simulation storage file, with filename extension BRS, to be written by *SIM/SIMD* and read by *TABLES*.

All of the various tables and data listings created by *TABLES* are applicable to either CRM or conventional simulations. The format of the tables and data listings are essentially the same for either CRM or conventional simulations. The primary difference in appearance is that whereas a conventional simulation is organized based on 12-month years, CRM simulation results are organized by sequences with lengths in months specified by the *SIM CR* record. Some tables provide additional information in the headings for CRM applications regarding the *CR* record parameters that define the organization of the hydrologic simulation sequences.

Reiterating, the difference between a conventional *WRAP* simulation and a CRM application is:

- A conventional simulation is based on sequential computations for the entire hydrologic period-of-analysis as a single simulation.

- In a CRM execution of *SIM* or *SIMD*, the hydrologic period-of-analysis is divided into many shorter simulation periods with the storage contents of each reservoir being reset to pre-specified initial levels at the beginning of each simulation period.

SIM/SIMD input files are the same for either a conventional or CRM simulation, except a conditional reliability *CR* record is added for a CRM simulation. The output filenames have the extensions OUT and CRM, respectively. The content and format of *SIM* output records are defined in Tables 5.2, 5.3, 5.4, and 5.5 of this *Reference Manual*. The first two parameters from the *CR* record are added to the 5th record of the *SIM* output file. The content and format of the individual water right, control point, and reservoir/hydropower output records are identical for CRM versus conventional simulations. The only difference in the output file format is the monthly sequencing of the records. All output is written within a monthly computational loop. As discussed below, the CRM annual option may exclude certain months of the year, and the monthly option may exclude a few months and may repeat years and months multiple times.

Multiple Short-Term Simulations with the Same Initial Storage

The variables entered on the *CR* record are shown in Table 8.1, which is also included in the *Users Manual*. Entering a *CR* record in the input file switches *SIM* or *SIMD* from the default conventional simulation mode to the conditional reliability modeling (CRM) mode.

Table 8.1
Conditional Reliability *CR* Record
(Reproduced from *Users Manual*)

field	columns	variable	format	value	description
1	1-2	CD	A2	CR	Record identifier.
2	3-8	CR1	I6	+ blank,0	Length of simulation period in months. Default = 12 months
3	9-16	CR2	I8	+ blank,0,−	Starting month (1, 2, ... ,12) for annual cycle option. Monthly cycle option is activated.
4	17-24	CR3	I8	blank,0,1 2	CRM file is limited to last 12 months of sequence. All months in CRM file for CR1 greater than 12. Applicable only if CR1 > 12 months.
5	25-32	CR4	F8.0	+ blank,0 ≤ −1.0	Factor by which all starting storages are multiplied. Default = 1.0 Storage multiplier factor = 0.0
6	33-40	CR5	I8	blank,0,1 2	Months excluded from CRM file are still simulated. Only the months written to CRM file are simulated. Default CR5 (blank field 6) is recommended.

The following parameters are specified on the *CR* record. CR1 has a default of 12 months if field 2 is left blank. The other *CR* record parameters are optional. CR3 and CR5 are applicable only if CR2 is non-zero.

CR1 is the length of the simulation period. Each hydrologic sequence is CR1 months long.

CR2 activates the annual cycle option and is the starting month of each sequence. Unlike the monthly cycle option, the annual cycle starts all simulation sequences in the same month.

CR3 is relevant only if the sequence length (CR1) is greater than 12 months. With CR1 greater than 12 months, the default option 1 is to record the simulation results for only the last 12 months in the *SIM* CRM output file for each simulation sequence. Option 2 is to record the simulation results for all CR1 months in the output file. CR3 affects application of *TABLES* frequency and reliability analyses.

CR4 is a factor by which all beginning reservoir storage volumes are multiplied (default=1.0)

CR5 is a switch used with the annual cycle option to skip simulations during the months of each year that are not used in the conditional reliability analyses. Option 1 is normally recommended. The sole purpose of CR5 option 2 is to save a little computer run time.

Specifying Simulation Sequences

The overall period of time for which stream inflows and evaporation-precipitation depths are included in the *SIM* FLO and EVA files is divided into multiple CRM simulation periods. The following two alternative approaches are provided for organizing the simulation periods.

1. The *annual cycle option* is defined as starting each simulation sequence in the same specified month (CR2 = 1, 2, 3, ... , 12) of the year. The annual cycle option is activated by a non-zero CR2 entered in *CR* record field 3.
2. The *monthly cycle option* is automatically activated if CR2 is zero (blank field 3). With the monthly cycle option, the multiple simulations with the same starting storage condition begin in different months with approximately the same number of simulations beginning in each of the 12 months of the year.

With either option, the hydrologic simulation sequence length may be any integer number of months. The annual cycle option captures seasonality. All of the simulations start in the same month of the year and represent the same seasons. However, the number of simulations is limited to the number of years in the total period-of-analysis or less. The monthly cycle option allows up to 12 times more simulations than the annual cycle option. With the monthly cycle option, the number of simulations is limited to the number of months indicated by Equation 7.1 presented later. The accuracy of frequency and reliability estimates depends both on properly modeling seasonal characteristics of hydrology and maximizing the number of hydrologic sequences used in the analyses. The choice of which option to adopt for a particular application depends upon the relative importance of these two considerations.

The message MSS file displays trace messages during a *SIM/SIMD* execution which are partially controlled by the variable ICHECK on the *JD* record. An ICHECK of 10 activates a trace written to the MSS file that shows the sequencing of years and months in the conditional reliability simulations. The trace is written within the computational loops and lists all months, shows the subdivision of months into simulation sequences, and indicates which months are excluded from the simulation results.

Annual Cycle Option

The *annual cycle option* is defined by a starting month (CR2) ranging from 1 to 12 and a simulation period (CR1) ranging from 1 to any integer number of months. Consider a *SIM* input dataset with a 1940-2000 hydrologic period-of-analysis which contains 61 years (732 months). The CRM sequences could be organized with a starting month of May (CR2 = 5) and simulation period of three months (CR1 = 3). Sixty-one simulation sequences would be defined as follows.

Sequence 1: May 1940 through July 1940
Sequence 2: May 1941 through July 1941
Sequence 3: May 1942 through July 1942
•••
Sequence 60: May 1999 through July 1999
Sequence 61: May 2000 through July 2000

Results are written to the output file for all of the months included in the simulation sequences. For the preceding example, the *WRAP-SIM* output file with filename extension CRM will contain results for May, June, and July for each of the 61 years.

As another example, assume that the starting month is set at May (CR2 = 5) and the simulation period (CR1) is the default of 12 months. The 61-year 1940-2000 overall hydrologic period-of-analysis is divided into the following 60 annual sequences. The 12 months January 1940 through April 1940 and May 2000 through December 2000 are not used. Sixty simulations are performed with the following hydrologic periods-of-analysis with each simulation starting with the same beginning-of-May reservoir storage contents.

Sequence 1: May 1940 through April 1941
Sequence 2: May 1941 through April 1942
•••
Sequence 60: May 1999 through April 2000

CR1 may exceed 12 months. Assume that the starting month is set at May (CR2 =5) and the simulation period (CR1) is 30 months. The 1940-2000 hydrologic period-of-analysis is divided into the following 59 annual sequences which are tabulated in Table 7.2. The six months January 1940 through April 1940 and November 2000 through December 2000 are not used.

Cycle 1

Sequence 1: May 1940 through October 1942
Sequence 2: May 1943 through October 1945
Sequence 3: May 1946 through October 1948
•••
Sequence 18: May 1991 through October 1993
Sequence 19: May 1994 through October 1996
Sequence 20: May 1997 through October 1999

Cycle 2

Sequence 21: May 1941 through October 1943
Sequence 22: May 1944 through October 1946
Sequence 23: May 1947 through October 1949
•••
Sequence 38: May 1992 through October 1994
Sequence 39: May 1995 through October 1997
Sequence 40: May 1998 through October 2000

Cycle 3

Sequence 41: May 1942 through October 1944
Sequence 42: May 1945 through October 1947
Sequence 43: May 1948 through October 1950
•••
Sequence 57: May 1990 through October 1992
Sequence 58: May 1993 through October 1995
Sequence 59: May 1996 through October 1998

Table 7.2
WRAP-SIM Conditional Reliability Modeling (CRM) Simulation Sequences for
Sequence Length CR1 of 30 Months and Starting Month CR2 of 5 (May)

Cycle 1			Cycle 2			Cycle 3		
1	May 40	Oct 42	21	May 41	Oct 43	41	May 42	Oct 44
2	May 43	Oct 45	22	May 44	Oct 46	42	May 45	Oct 47
3	May 46	Oct 48	23	May 47	Oct 49	43	May 48	Oct 50
4	May 49	Oct 51	24	May 50	Oct 52	44	May 51	Oct 53
5	May 52	Oct 54	25	May 53	Oct 55	45	May 54	Oct 56
6	May 55	Oct 57	26	May 56	Oct 58	46	May 57	Oct 59
7	May 58	Oct 60	27	May 59	Oct 61	47	May 60	Oct 62
8	May 61	Oct 63	28	May 62	Oct 64	48	May 63	Oct 65
9	May 64	Oct 66	29	May 65	Oct 67	49	May 66	Oct 68
10	May 67	Oct 69	30	May 68	Oct 70	50	May 69	Oct 71
11	May 70	Oct 72	31	May 71	Oct 73	51	May 72	Oct 74
12	May 73	Oct 75	32	May 74	Oct 76	52	May 75	Oct 77
13	May 76	Oct 78	33	May 77	Oct 79	53	May 78	Oct 80
14	May 79	Oct 81	34	May 80	Oct 82	54	May 81	Oct 83
15	May 82	Oct 84	35	May 83	Oct 85	55	May 84	Oct 86
16	May 85	Oct 87	36	May 86	Oct 88	56	May 87	Oct 89
17	May 88	Oct 90	37	May 89	Oct 91	57	May 90	Oct 92
18	May 91	Oct 93	38	May 92	Oct 94	58	May 93	Oct 95
19	May 94	Oct 96	39	May 94	Oct 97	59	May 96	Oct 98
20	May 97	Oct 99	40	May 97	Oct 00			

With the annual cycle option, if the sum of CR1 and CR2 is 13 or less, the number of sequences equals the number of years reflected in the hydrology dataset (*IN* and *EV* records). If CR1 is 12 or less and the sum of CR1 and CR2 exceeds 13, the number of sequences used in the CRM analysis is one less than the number of years of hydrology. If CR1 exceeds 12 months, the number of sequences will be less than the number of years but may be less by more than one.

CR3 and CR5 Options

The parameters CR3 and CR5 entered in *CR* record fields 4 and 5 apply only to the annual cycle option. CR3 and CR5 are relevant only if CR2 is non-zero meaning a starting month is specified. CR3 is relevant only if CR1 is greater than 12 months. The sequence length CR1 may range from one to 12 times the number of years of hydrology data (*IN* and *EV* records). CR3 controls the number of months that are recorded in the simulation results output file.

CR3 does not affect the *SIM* simulation computations but rather controls whether all or only a portion of the simulation results are recorded in the *SIM* output CRM file. The default CR3 option 1 consists of recording the simulation results in the CRM file for only the last 12 months for each simulation sequence. Option 2 is to record the simulation results for all CR1 months in the *SIM* output CRM file.

The choice of *SIM* CR3 option depends upon options to be employed in *TABLES* to create frequency and reliability tables. *TABLES* 2FRE, 2FRQ, 2REL, and 2RES records include options for specifying a specific month for which tables are to be created. For example, based on the results of the *SIM* simulation illustrated in Table 7.2, a *TABLES* 2FRE record storage-frequency table may be developed for reservoir storage contents at the end of August, twenty-eight months after starting with a specified beginning-of-May storage. Each of the fifty-eight 30-month simulation sequences include three Augusts but only the last August of each sequence is relevant to the frequency analysis. Thus, CR3 option 1 is employed.

Another analysis might entail a 2REL water supply diversion reliability table with reliabilities defined based on meeting diversion targets during the entire 30-month simulation period. Although the CRM starting storage content is specified for the beginning-of-May, the diversion reliabilities are not for a specific month of the year. Thus, CR3 option 2 is applicable.

The optional parameter CR5 is related to the months that are not included in the simulation period. In the previous example of a 3-month simulation period starting in May (CR1=3 and CR2=5), January-April and August-December are not included in the simulation period. However, with the default (blank *CR* record field 6) CR5 option 1, all months including January-April and August-December as well as May-July are included in the simulation computations even though the results for January-April and August-December are not recorded in the *SIM* simulation results CRM file. The default CR5 option 1 is normally recommended. The only reason for selecting the alternative CR5 option 2 is to reduce computer run time. CR5 applies only to the annual cycle option. All months are simulated with the monthly cycle option even though a few of the months are not included in the CRM file simulation results.

With the default CR5 option 1, all 12 months are simulated each year regardless of whether they are included in the simulation period defined by CR1 and CR2. Only the results for the months actually included in the specified simulation period are written to the output file. CR5 allows the computations to be skipped for the months not included in the CR1/CR2 defined simulation period. However, results associated with the next-month return flow option and next-month hydropower return flow option may be affected by the choice of whether or not all months are simulated. With these next-month options in effect, return flows or hydropower releases during the last month of a year or simulation sequence enter the stream system in the first month of the next year or sequence. Certain target setting options activated by *TO* records are also based on amounts from the preceding month and thus may be affected by the CR5 switch.

Monthly or Non-Annual Cycle Option

The *monthly (non-annual) cycle option* is the other alternative for organizing CRM simulation sequences. This approach allows creation of a greater number of sequences by removing the restriction that all sequences start in the same specified month. With the monthly cycle option, the first sequence begins in the first month of the first year and has the length specified by CR1. The second sequence begins in the next month following completion of the first sequence. The sequencing recycles after reaching the end of the last year. Each cycle begins one month after the preceding cycle. The number of complete sequences is:

$$\text{number of sequences} = (12)(\text{number of years}) - \text{CR1} + 1 \tag{2.1}$$

Applying the monthly cycle option to the 1940-2000 example, for a CR1 of 4 months, 729 sequences will be created as follows with the computations performed and the simulation results output in the following order.

<u>Cycle 1</u>

Sequence 1: January 1940 through April 1940
Sequence 2: May 1940 through August 1940
Sequence 3: September 1940 through December 1940
Sequence 4: January 1941 through April 1941
•••
Sequence 179: May 1999 through August 1999
Sequence 183: September 1999 through December 1999

<u>Cycle 2</u>

Sequence 184: February 1940 through May 1940
Sequence 185: June 1940 through September 1940
•••
Sequence 364: February 2000 through May 2000
Sequence 365: June 2000 through September 2000
Three months not used: October–December 2000

<u>Cycle 3</u>

Sequence 366: March 1940 through June 1940
Sequence 367: July 1940 through October 1940
•••
Sequence 546: March 2000 through June 2000
Sequence 547: July 2000 through October 2000
Two months not used : November–December 2000

<u>Cycle 4</u>

Sequence 548: April 1940 through July 1940
Sequence 549: August 1940 through November 1940
•••
Sequence 728: April 2000 through July 2000
Sequence 729: August 2000 through November 2000
One month not used: December 2000

<u>Specifying Initial Storage Contents of Each Reservoir</u>

In conditional reliability modeling, the same initial reservoir storage contents are reset at the beginning of each of the simulations. *SIM/SIMD* options for specifying initial storages do not differentiate between a conventional and CRM simulation other than the factor CR4 entered on the *CR* record. Initial storage content may be entered in *WS* record field 8 for individual reservoirs. Initial storages may be entered as a beginning-ending-storage BES file (*JO* record field 5) for any or all reservoirs. Initial storage content is automatically set equal to the storage capacity by default for any reservoir for which an initial storage is not otherwise specified.

CR4 entered on the *CR* record is a factor by which the initial storage of all reservoirs is multiplied. For example, to set the initial storage in all reservoirs at 75 percent of capacity, a value of 0.75 may be entered on the *CR* record for CR4 with initial storages not otherwise specified and thus defaulting to capacity. With 0.75 entered for CR4, each simulation sequence begins with the storage level of each reservoir at 75 percent of the beginning-of-simulation storage contents otherwise specified.

***TABLES* Equal-Weight versus Probability Array Strategies**

Two alternative strategies, called the *equal-weight option* and *probability array option*, are provided for *TABLES* to associate probabilities with each of the multiple simulation sequences generated by *SIM* or *SIMD*. With the *equal-weight option*, the reliability and frequency computations activated by *2REL, 2FRE, 2FRQ*, and *2RES* records are the same for either a CRM analysis or conventional long-term simulation. Each simulation sequence is weighted equally or counted once in applying the basic equations (Eqs. 7.2−7.7) covered in the following discussion. The alternative *probability array option* activated by the *5CR1* and *5CR2* records covered in the latter half of this chapter is based on developing an array assigning probabilities to the multiple simulation sequences as a function of preceding storage.

The default equal-weight approach is simple and generally valid. It is covered first in the following presentation and then illustrated with an example. Most of the complexity of this chapter is associated with the optional probability array option methods for enhancing probability estimates associated with the individual simulations, which are presented later after the example applying the equal-weight option.

Reliabilities associated with meeting water supply diversion, hydroelectric power generation, and environmental instream flow targets over the next several months and the amount of water contained in storage at the end of the next several months depend on both the:

1. amount of water currently available in reservoir storage
2. hydrology that occurs over the future several-month period of interest as represented by naturalized flows and net reservoir evaporation rates

Beginning reservoir storage and naturalized stream flow represent the two sources of available water. The relative importance of these two sources in determining water supply reliabilities and end-of-period reservoir storage frequencies depends upon their relative magnitude. Beginning reservoir storage is specified by the model-user as input to the *SIM* simulation. The conditional reliability modeling (CRM) options outlined in the latter half of this chapter focus on the hydrology, particularly on relating the probabilistic characteristics of the multiple sequences of naturalized stream flows to specified known beginning storage conditions.

The relative importance of beginning storage versus hydrology over the time period of interest is a key consideration governing the choice between the *equal-weight* and *probability array* options. The other key factor is the degree of correlation between naturalized flow over the period of interest and the known preceding storage contents. The last section of the chapter is a comparative summary of the alternative methodologies.

Program *TABLES* Reliability and Frequency Tables

The program *TABLES* performs reliability and frequency analyses using the simulation results read from a *SIM* or *SIMD* output file. *TABLES* also contains routines that simply reorganize and tabulate the simulation results as user-specified tables. The *TABLES* routines applied in conventional applications are also applicable to CRM. The tables created for conventional non-CRM applications have the same format and content when used with CRM. However, frequency and reliability indices are interpreted differently for different types of applications. The CRM frequency and reliability estimates always reflect user-specified preceding reservoir storage contents and multiple hydrologic simulation sequences.

The *2REL* record creates reliability tables for diversion or hydropower targets for water rights, water right groups, control points, or reservoirs. The *2FRE* and *2FRQ* records create frequency tables for naturalized flow, regulated flow, unappropriated flow, reservoir storage volume, reservoir surface elevation, and instream flow shortage. The *2RES* record creates reservoir draw-down frequency and storage reliability tables. The tables may be developed from the results of either a conventional simulation or CRM simulation with any of the CRM options.

TABLES reliability and frequency tables are based on the concepts expressed by Equations 7.2–7.7 and described by the remainder of this chapter. With a dataset for a conventional WRAP simulation available, the switch from conventional long-term modeling to short-term conditional reliability modeling can be simple with little additional input required or significantly more complex depending upon the CRM options adopted. The probability array options are more complicated than the equal-weight approach.

Reliability and frequency indices may consider all months or alternatively may be for a specified month. For example, a frequency table may be created for regulated flows at specified control points during August or end-of-month storage contents for August. Likewise, a reliability table may be constructed for meeting water supply diversion targets in any randomly selected future month or alternatively may be defined for a particular month such as August.

Reliability Analyses of Water Supply Diversions and Hydropower Generation

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 *TABLES* reliability summary includes tabulations of period reliabilities expressed both as the percentage of months and the percentage of years (or CRM sequences) during the simulation during which either 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/SIMD* simulation as:

$$R_P = \frac{n}{N} \ (100\%) \tag{7.2}$$

where n denotes the number of periods during the simulation for which the specified percentage of the demand is met, and N is the total number of periods considered.

Volume reliability is the percentage of the total demand that is actually supplied. For water supply diversions, the demand is a volume. For hydropower, the demand is energy generated. Volume reliability (R_V) is the ratio of the total diversion volume supplied or energy produced (v) to the total volume or energy target demanded (V) during a specified period of time.

$$R_V = \frac{v}{V} \ (100\%) \tag{7.3}$$

Equivalently, R_V may be viewed as the ratio of the mean actual water supply diversion rate to mean target diversion rate or the ratio of the mean energy production rate to mean target rate.

In either a conventional or CRM application, *TABLES* applies Eqs. 7.2 and 7.3 using data from the simulation results output file created by *SIM* or *SIMD*. For a conventional simulation, the reliability indices are expressions for capabilities for meeting water supply, hydropower, instream flow, and reservoir storage requirements in the long-term without consideration of the amount of water in storage today. In a CRM application, the reliabilities reflect capabilities for meeting these requirements during the next several months or in a particular month in the near future given known preceding reservoir storage levels. Short-term CRM reliabilities are conditioned on known initial reservoir storage contents.

Frequency Analyses of Stream Flow and Reservoir Storage

In general, exceedance frequency, expressed as a percentage ranging from 0 to 100%, or exceedance probability, expressed as a fraction between 0 and 1.0, represents the estimated likelihood of equaling or exceeding particular values of a random variable. Exceedance frequency is an expression of the percentage of time that particular flow or storage amounts can be expected to occur or equivalently the probability of a certain amount of water being available. *TABLES* provides options to model the probabilistic nature of naturalized flows, regulated flows, unappropriated flows, instream flow shortages, reservoir storage volume, and reservoir water surface elevation in terms of relative frequency (Equation 7.4) or alternatively using the normal or log-normal probability distribution functions (Eqs. 7.6 and 7.7).

From a relative frequency perspective, exceedance frequency (F) and exceedance probability (P) are expressed as:

$$F = \frac{n}{N} \ (100\%) \tag{7.4}$$

$$P = \frac{n}{N} \tag{7.5}$$

where n is the number of time periods that a specified amount is equaled or exceeded and N is the total number of time periods considered. Exceedance frequency is computed in the *TABLES 2FRE*, *2FRQ*, and *2RES* record routines based on Equation 7.4 with n being the number of months during the *SIM* simulation that a particular flow or storage amount is equaled or exceeded. N is the total number of months considered.

Alternatively, the *TABLES 2FRE* record provides options to apply the normal or log-normal probability distributions to the series of monthly flow and storage volumes generated by *SIM*. The random variable X in Eq. 7.6 may be naturalized flows, regulated flows, unappropriated flows, instream flow shortages, or reservoir storage volumes or elevations.

$$X = \overline{X} + z\,S \tag{7.6}$$

The frequency factor (z) is derived from a normal probability table, and $\overline{X}$ and S denote the sample mean and standard deviation of the data read from the *SIM* output file.

The log-normal distribution consists of the normal distribution applied to the logarithms of X, with Eq. 7.6 expressed as Eq. 7.7 with z still derived from the normal distribution.

$$\log X = \overline{\log X} + z\,S_{\log X} \tag{7.7}$$

In the probability distribution options activated by the *2FRE* record, exceedance probabilities are assigned to the random variable X by fitting the normal or log-normal distribution in a standard manner outlined in statistics textbooks. The mean $\overline{\log X}$ and standard deviation $S_{\log X}$ of the logarithms of the data from the *SIM* output file are computed. The frequency factor z for specified exceedance probabilities from a normal probability table are built into *TABLES*.

CRM frequency analyses are typically performed with *TABLES* for a particular month using *SIM* simulation results reflecting the annual cycle hydrologic sequencing option. For example, a 2FRE reservoir storage-frequency table may be developed for the storage content at the end-of-October conditioned upon a specified storage content at the beginning-of-May. The storage-frequency relationship developed with *TABLES* refers specifically to storage at the end of October computed by *SIM* based upon a given storage content occurring six months earlier. The *SIM* annual cycle option is required for this analysis. The monthly cycle option is not valid for applications that specify specific months of the year. With the annual cycle option with a sequence length exceeding 12 months, the same month can occur multiple times in each sequence, but only one of the concurrences of that month is adopted in the frequency computations. *TABLES* includes warning and error messages designed to prevent inappropriate use of the options specifying a month in CRM analyses. However, the user must also apply caution in this regard in meaningfully applying the analysis capabilities of *SIM* and *TABLES*.

<u>Program TABLES Input Records and Resulting Tables</u>

The default equal-weight CRM option consists of performing the reliability and frequency computations activated by *2REL*, *2FRE*, *2FRQ*, and *2RES* records identically the same for a CRM analysis as with a conventional long-term simulation. The format and content of the *SIM/SIMD* output file records are the same with either a conventional or CRM simulation. Program *TABLES* reads the *SIM/SIMD* simulation results and processes the data through reliability and frequency algorithms that are not affected by whether the data was generated by a single conventional long-term simulation or multiple equally-weighted CRM simulations. Of course, resetting initial storage contents does significantly affect the numerical values reflected in the *SIM/SIMD* simulation results and corresponding *TABLES* frequency and reliability analyses results. Information from the *CR* record is included in the table headings.

Although the content and format of the *SIM*/*SIMD* output file records are the same for either CRM or conventional non-CRM applications, the total number of output records varies with variations in the number of years and months. For a conventional simulation, there are 12 months in each year. With the CRM annual cycle option with sequence length $\text{CR1} \leq 12$, there are CR1 months for each year, but the number of sequences is either the number of years or one less. With the CRM monthly cycle option, there are also CR1 months for each sequence, but the number of sequences given by Equation 7.1 approaches the total number of months in the overall period-of-analysis. In all cases, the *TABLES* routines cycle through *SIM* simulation results organized by groups of months contained within years. For each month, the output records are organized by user-specified groups of control points, water rights, and reservoirs.

Reliability indices are developed by *TABLES* as specified by a *2REL* record. Frequency tables are created with a *2FRE* or *2FRQ* record. Storage reliabilities and draw-down frequencies are determined with a *2RES* record. Reliabilities are computed for either water supply diversion or hydroelectric energy targets for individual water rights, the aggregation of all rights associated with individual control points or reservoirs, groups of selected rights, or the aggregation of all rights in the model. *2FRE* and *2FRQ* frequency tables may be developed 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

Reliability and frequency analyses may be performed for a specified individual month of the year or for the aggregation of all the months included in the simulation. All 12 months of the year are included in a conventional *SIM* simulation. For a CRM analysis, the months for which reliabilities and frequencies may be computed are those included in the *SIM* simulation sequences as defined by the *CR* record. The annual portion of a reliability table refers to the aggregation of 12 months for a conventional simulation and the number of months entered for CR1 on the *CR* record for a CRM analysis. For the annual cycle option, if CR1 exceeds 12 months, the *CR* record parameter CR3 may be applied to limit the *SIM* simulation results recorded in the CRM file to the last 12 months of each simulation sequence.

A *5CRM* record activates the CRM mode of analysis. The *2REL* record diversion or hydropower reliability tables, *2RES* reservoir storage tables, and *2FRE* and *2FRQ* record flow and storage frequency tables are used to display the results of either CRM or conventional non-CRM analyses. Additional routines activated by the *5CR1* and *5CR2* records described later in this chapter develop the storage-flow-frequency (SFF) or flow-frequency (FF) relationship and incremental probability (IP) array used in the CRM probability distribution option for assigning probabilities to the multiple simulation sequences. Without the *5CR1* and *5CR2* records, all of the simulation sequences are weighted equally in applying Equations 2.2−2.7. The format of the tables created with the *2REL*, *2FRE*, *2FRQ*, and *2RES* records are the same with or without the probability distribution option routines activated by the *5CR1* and *5CR2* records, though the numerical values are of course dependent upon the options adopted for the computations. Table headings include information from the *SIM CR* record regarding organization of the CRM simulation sequences.

5CRM, *5CR1*, *5CR2*, and *5COR* records are the only *TABLES* input records used solely for conditional reliability modeling. The *5CRM* record simply tells *TABLES* to open a *SIM* CRM output file in preparation for performing CRM analyses. The *5CR1* and *5CR2* records control the optional routines for assigning probabilities to the simulation sequences. The *5COR* record is used to compute correlation coefficients that measure the degree of linear correlation between naturalized flow volumes and preceding reservoir storage volumes at selected control points. The correlation coefficients provide information that is useful in selecting reservoirs, control points, time periods, and computational options for use in the procedures that assign probabilities to the multiple simulation sequences. The *5CRM* record is the only extra record required for conditional reliability modeling if the simulation sequences are weighted equally, with each sequence counted once in the frequency and reliability analysis counts.

Conditional Reliability Modeling (CRM) Example 7.1

Examples presented in this chapter are expanded versions of the example in the *Fundamentals Manual.* The system consists of eleven control points, six reservoirs, and 30 water rights. The hydrologic period-of-analysis is 1940-1997. The three CRM examples in Chapter 7 consist of converting the conventional simulation presented in the *Fundamentals Manual* to conditional reliability modeling applications. Storage frequencies and water supply reliabilities are conditioned upon specified preceding reservoir storage conditions.

The default CRM equal-weight option is implicitly adopted for the conditional reliability analysis of the following CRM Example 7.1, meaning that each of the N multiple short-term hydrologic sequences is equally-weighted or counted once in applying Equations 7.2, 7.3, and 7.4. A *SIM CR* record and *TABLES 5CRM* record are the only additional input records required to convert from the conventional long-term simulation mode to the short-term CRM mode using the equal-weight option. CRM Examples 7.2 and 7.3 presented later in this chapter apply the alternative probability array approach that employs 5CR1 and 5CR2 records. The three CRM examples use the same *SIM* input dataset (DAT, FLO, and EVA files) and *SIM* simulation results (CRM file) but adopt different *TABLES* modeling capabilities and associated input records.

The *SIM* input dataset for the example in the *Fundamentals Manual* consists of DAT, FLO, and EVA files. The three CRM examples use the same FLO and EVA files without change. The following *CR* record is inserted following the *JO* record in the DAT file shown in the *Fundamentals Manual*.

```
CR    12      4      0     0.10
```

The parameters entered on the *CR* record are defined by Table 7.1 presented earlier in this chapter. The *CR* record in this example divides the 1940-1997 period-of-analysis into 57 twelve-month hydrologic sequences extending from April (month 4) through March (month 3). Although not activated in this example, *JD* record ICHECK option 10 provides a listing in the *SIM* message file showing the subdivision of months into hydrologic simulation sequences.

The CR2 value of 4 means that each of the 57 simulations begins in April with the same user-specified beginning-of-April reservoir storage contents. Although several options are available for specifying beginning-of-simulation storage, the example adopts the combined options of the *SIM* default of starting at full to capacity which is modified by the CR4 multiplier factor of 0.10. The reservoirs all have beginning-of-month storage contents for each April of 10.0 percent of their storage capacities.

The initial few output records of the *SIM* simulation results output file, with filename extension CRM, is reproduced as Table 7.3. The CRM file contains *SIM* simulation results for months 4 through 3 (April through March) for 57 years (April 1940 – March 1997). The variables are defined in Tables 5.2-5.5 of this *Reference Manual*. CRM and OUT files contain the same variables in the same format. Program *TABLES* reads the CRM file and develops a TOU file in accordance with specifications provided by a TIN file as explained in the *Users Manual*.

Table 7.3
Beginning of *SIM* Output CRM File for the CRM Example

```
WRAP-SIM (August 2012 Version) CRM Output File
  SIM Input File CrmExam1.DAT
  CRM Example in Chapter 7 of Reference Manual
  Fundamentals Manual Example Converted to CRM by Adding CR Record
  1940    58    11    29     6    12     4     0   0.100
IF   4       0.00       0.00       0.00       0.00       0.00       0.00       0.00          IF-1     295.89       0.00         4 1940
IF   4       0.00       0.00       0.00       0.00       0.00       0.00       0.00          IF-2    9863.01       0.00         4 1940
1940 4      0.000   4320.000    -224.12   51869.12   36755.00   36755.00       0.00          WR-6WacoLake             1512.00       0.00
1940 4      0.000    705.600     542.10   72548.30   16772.00   16772.00       0.00          WR-1      PK              246.96       0.00
1940 4      0.000  20375.752     475.51   52239.14       0.00       0.00       0.00          WR-2      PK                0.00       0.00
1940 4      0.000    361.600       0.00       0.00     361.60  110479.30       0.00         WR-14 Cameron               36.16       0.00
1940 4      0.000   1104.000       0.00       0.00    1104.00  178427.66       0.00         WR-20   Bryan               55.20       0.00
1940 4      0.000   1587.200       0.00       0.00    1587.20  172890.56       0.00         WR-22    Hemp                0.00       0.00
1940 4      0.000   1033.600       0.00       0.00    1033.60   77913.92       0.00         WR-16WacoGage                0.00       0.00
1940 4      0.000   1433.600       0.00       0.00    1433.60  101203.09       0.00         WR-17Highbank                0.00       0.00
1940 4      0.000   1765.400       0.00       0.00    1765.40  110117.70       0.00         WR-13 Cameron              882.70       0.00
1940 4      0.000   3783.000       0.00       0.00    3783.00  171571.44       0.00         WR-19   Bryan             2458.95       0.00
1940 4      0.000   9273.200       0.00       0.00    9273.20  163593.73       0.00         WR-21    Hemp                0.00       0.00
1940 4      0.000   5958.720     -38.21   69774.49   29935.00   29935.00       0.00          WR-8  Belton             2681.42       0.00
1940 4      0.000   8108.717     -36.69   61664.25       0.00       0.00       0.00          WR-9  Belton             1621.74       0.00
1940 4      0.000   1768.859       2.08    5958.06    4019.00    4019.00       0.00         WR-10  George              849.05       0.00
1940 4      0.000   2900.901     -45.70   13488.01    9793.20    9793.20       0.00         WR-11 Granger             1160.36       0.00
1940 4   1296.000   1296.000    -294.03   88716.36   25712.33   25712.33       0.00          WR-3 Whitney                0.00       0.00
1940 4      0.000   2947.200       0.00       0.00    2947.20   67678.80       0.00         WR-12 Cameron             1031.52       0.00
1940 4      0.000   1754.354       0.00       0.00    1754.35   91354.17       0.00         WR-18   Bryan              701.74       0.00
1940 4      0.000   1497.600    -222.59   50369.99       0.00       0.00       0.00          WR-7WacoLake              599.04       0.00
1940 4      0.000   6078.078       0.00       0.00    6078.08   64731.60       0.00         WR-15 SystemC             2127.33       0.00
1940 4      0.000   2384.000       0.00       0.00    2384.00   81647.02       0.00         WR-23    Hemp                0.00       0.00
1940 4      0.000  62162.160       0.00       0.00   62162.16   79263.02       0.00         WR-24 SystemH                0.00       0.00
1940 4      0.000      0.000    -294.03   88716.36       0.00       0.00       0.00          WR-5  Refill                0.00       0.00
1940 4      0.000      0.000     475.51   52239.14       0.00       0.00       0.00         WR-25  Refill                0.00       0.00
1940 4      0.000      0.000     -36.69   61664.25       0.00       0.00       0.00         WR-26  Refill                0.00       0.00
1940 4      0.000      0.000       2.08    5958.06       0.00       0.00       0.00         WR-27  Refill                0.00       0.00
1940 4      0.000      0.000     -45.70   13488.01       0.00       0.00       0.00         WR-28  Refill                0.00       0.00
    PK      0.000  21081.352     475.51   52239.14   16772.00       0.00       0.00   16772.00       0.00    1023.09       0.00       0.00
  Whit   1296.000   1296.000    -294.03   88716.36   25712.33       0.00     233.24   41228.00       0.00     373.15       2.10       0.00
 WacoL      0.000   5817.600    -222.59   50369.99   36755.00       0.00       0.00   36755.00       0.00       0.00       0.00       0.00
 WacoG      0.000   1033.600       0.00       0.00    1033.60   17968.07   28986.95  101058.00   51399.40     788.77     292.18       0.00
  High      0.000   1433.600       0.00       0.00    1433.60   17788.39       0.00  125139.00   74543.38    1113.30     404.96       0.00
Belton      0.000  14067.438     -36.69   61664.25   29935.00       0.00       0.00   29935.00       0.00     838.18       0.00       0.00
George      0.000   1768.859       2.08    5958.06    4019.00       0.00       0.00    4019.00       0.00      32.15       0.00       0.00
 Grang      0.000   2900.901     -45.70   13488.01    9793.20       0.00     849.05   12931.00       0.00     206.70      12.74       0.00
 Camer      0.000  11152.277       0.00       0.00   11152.28   18194.35    5060.55  106875.00   58949.41    1937.61     212.29       0.00
 Bryan      0.000   6641.354       0.00       0.00    6641.35   17539.35    3427.10  232186.00  132884.25    3423.36     940.82       0.00
  Hemp      0.000  75406.562       0.00       0.00   75406.56   17100.87    2907.73  196282.00   26963.88       0.00       0.00       0.00
    PK       0.00       0.00     475.51   52239.14   16772.00       0.00   21081.35       0.00     0.1910     0.1910      0.000 570240.0
  Whit    2250.00       0.00    -294.03   88716.36   25712.33       0.00       0.00       0.00    -0.0700    -0.0700    491.381 627100.0
 WacoL       0.00       0.00    -222.59   50369.99   36755.00       0.00    5817.60       0.00    -0.0630    -0.0630      0.000 192100.0
Belton       0.00       0.00     -36.69   61664.25   29935.00       0.00   14067.44       0.00    -0.0120    -0.0120      0.000 457600.0
George       0.00       0.00       2.08    5958.06    4019.00       0.00    1768.86       0.00     0.0060     0.0060      0.000  37100.0
 Grang       0.00       0.00     -45.70   13488.01    9793.20       0.00    2900.90       0.00    -0.0400    -0.0400      0.000  65500.0
```

The *TABLES* TIN input file for Example 7.1 is reproduced as Table 7.4. The *5CRM* record activates the conditional reliability modeling (CRM) mode, with *TABLES* reading a *SIM* output file with extension CRM rather than OUT. CRM information is also included in the table headings generated by *TABLES*. Without the *5CR1* and *5CR2* records discussed later in this chapter, the *TABLES* computational routines are the same for the CRM application as with a conventional simulation. Of course, the reliabilities and frequencies in the example are conditioned upon all reservoirs having storage contents of 10 percent of capacity at the beginning of April.

Table 7.4
TABLES Input TIN File for CRM Example 7.1

```
**   TABLES Input File CrmExam1.TIN
**   CRM Example 1 in Chapter 7 of Reference Manual
5CRM
****     1         2         3         4         5         6
****567890123456789012345678901234567890123456789012345678901234
****---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!
**    Reliability Tables
2REL   0   0   1
2REL   0   0   0   0   0   0   1
****---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!
**    Frequency Tables
2FRE   2
2FRE   2   9   0   2
2FRE   6   6
2FRE   6   9
2FRE   6   3
2FRQ   6   3   5  Belton  50000. 100000. 200000. 400000. 450000.
****---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!
**    Reservoir Content, Drawdown, and Reliability Tables
2RES   4   6   6      PK    Whit   WacoL  Belton  George   Grang
2RES              570240. 627100. 192100. 457600.  37100.  65500.
2RES                   0. 379000.    580.      0.    240.    220.
2RES   4   9   6      PK    Whit   WacoL  Belton  George   Grang
2RES              570240. 627100. 192100. 457600.  37100.  65500.
2RES                   0. 379000.    580.      0.    240.    220.
****---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!
**    Reservoir Storage Table
UNIT            APR
2STO   1   0   0   2   1
IDEN   Grang
ENDF
```

The two reliability tables in Table 7.5 are reproduced from the TOU file created by *TABLES* in accordance with the *2REL* records shown in Table 7.4. With the exception of the CRM information added to the headings, these tables have the same format for either CRM or conventional analyses. The first reliability table in Table 7.5 shows reliabilities for each of the water rights. The second table shows reliabilities for the aggregation of all water rights at each control point. The reliabilities in the two tables are associated with meeting water supply diversion requirements during the 12-month period from April through March given that reservoir storage contents are at 10 percent of capacity at the beginning of April.

Table 7.5
Reliability Tables for CRM Example 7.1 Created with 2REL Records

RELIABILITY SUMMARY FOR SELECTED WATER RIGHTS

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

NAME	TARGET DIVERSION (AC-FT/SQ)	MEAN SHORTAGE (AC-FT/SQ)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	++++++++ PERCENTAGE OF MONTHS ++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT							-------- PERCENTAGE OF SEQUENCES --					
					100%	95%	90%	75%	50%	25%	1%	100%	98%	95%	90%	75%	50%
WR-6	60000.0	1031.64	97.51	98.28	97.5	97.5	97.7	97.8	98.2	98.7	99.6	91.2	93.0	93.0	93.0	96.5	100.0
WR-1	9800.0	192.57	97.22	98.04	97.2	97.2	97.5	97.8	98.1	98.4	98.8	82.5	84.2	87.7	93.0	96.5	100.0
WR-2	245000.0	20592.22	88.01	91.60	88.0	88.3	88.6	89.2	90.9	92.8	96.9	63.2	63.2	63.2	70.2	89.5	98.2
WR-14	11300.0	145.33	98.68	98.71	98.7	98.7	98.8	99.0	99.0	99.1	99.3	87.7	89.5	91.2	93.0	100.0	100.0
WR-20	34500.0	509.46	98.68	98.52	98.7	98.7	98.8	99.0	99.3	99.6	99.6	86.0	86.0	89.5	96.5	98.2	100.0
WR-22	49600.0	2055.89	97.37	95.86	97.4	97.5	97.7	97.8	98.4	98.7	99.0	78.9	78.9	84.2	86.0	93.0	98.2
WR-16	32300.0	4095.71	92.11	87.32	92.1	92.5	92.8	93.4	94.6	95.0	95.2	47.4	52.6	54.4	61.4	73.7	94.7
WR-17	44800.0	7191.16	90.94	83.95	90.9	91.2	91.7	92.5	93.9	95.3	95.9	45.6	47.4	50.9	52.6	70.2	91.2
WR-13	18200.0	948.71	95.61	94.79	95.6	95.6	95.6	95.8	96.1	96.2	96.2	71.9	71.9	71.9	73.7	93.0	100.0
WR-19	39000.0	2163.42	95.47	94.45	95.5	95.6	95.6	95.9	95.9	95.9	96.2	70.2	71.9	71.9	73.7	91.2	100.0
WR-21	95600.0	6802.02	93.27	92.88	93.3	93.9	93.9	94.0	94.7	95.2	95.6	61.4	64.9	66.7	70.2	86.0	98.2
WR-8	82760.0	9780.20	85.38	88.18	85.4	85.7	86.1	87.0	88.0	89.9	93.0	57.9	57.9	59.6	66.7	78.9	93.0
WR-9	97500.0	15439.90	82.60	84.16	82.6	83.0	83.0	83.0	83.8	84.2	85.2	56.1	56.1	57.9	59.6	75.4	86.0
WR-10	25610.0	6512.08	67.69	74.57	67.7	68.4	68.7	70.2	72.7	78.7	92.3	33.3	35.1	38.6	40.4	49.1	77.2
WR-11	42000.0	6892.19	78.51	83.59	78.5	78.7	78.8	80.8	84.6	88.2	93.3	49.1	50.9	50.9	52.6	68.4	89.5
WR-3	18000.0	10732.51	41.67	40.37	41.7	41.8	41.8	42.0	42.3	42.4	42.7	3.5	3.5	3.5	19.3	29.8	36.8
WR-12	92100.0	33996.59	79.24	63.09	79.2	79.7	80.0	80.8	83.3	86.5	89.3	15.8	15.8	17.5	17.5	38.6	63.2
WR-18	25400.0	4481.31	84.50	82.36	84.5	84.5	84.5	84.6	85.4	85.7	86.1	35.1	35.1	38.6	42.1	70.2	91.2
WR-7	20800.0	516.80	97.37	97.52	97.4	97.4	97.4	97.4	97.5	97.5	97.5	91.2	91.2	91.2	93.0	93.0	100.0
WR-15	88000.0	10627.16	86.70	87.92	86.7	86.7	87.1	88.3	89.0	90.5	91.4	57.9	63.2	63.2	64.9	80.7	91.2
WR-23	74500.0	26866.12	81.14	63.94	81.1	81.1	81.1	81.9	83.2	84.2	84.9	24.6	24.6	28.1	33.3	40.4	59.6
WR-24	900000.0	100138.59	86.11	88.87	86.1	86.3	86.5	87.4	88.9	91.7	94.4	57.9	61.4	63.2	70.2	80.7	94.7
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	271711.56		87.10													

As an example of interpreting reliabilities, water right WR-6 has a diversion target of 60,000 acre-feet during the 12-month period April-March. The period reliability of 97.51% in the table above means that the monthly targets is fully supplied during 97.51% of the 684 months simulated. The volume reliability of 98.28% represents the percentage of the total target volume that is supplied during the 684 months. At least 97.7% of the monthly target is met during 90% of the 684 months simulated. The annual diversion was at least 91.2% and 93.0% of the 60,000 acre-feet target during 100% and 90% of the 57 annual (April-March) sequences.

Reliability tables may also be developed for a specified month such as August. With reliability tables generated for a specified month, only diversion data for that month is used is computing the values shown in the second through 12th columns of the table. However, the 13th through 18th columns are annual period reliabilities for the year or entire sequence length.

Table 7.5 (Continued)
Reliability Tables for CRM Example 7.1 Created with 2REL Records

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

NAME	TARGET DIVERSION (AC-FT/SQ)	MEAN SHORTAGE (AC-FT/SQ)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	+++++++++ PERCENTAGE OF MONTHS +++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	-------- PERCENTAGE OF SEQUENCES -------- PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
PK	254800.0	20784.78	88.01	91.84	88.0	88.3	88.6	89.2	90.9	93.1	98.5	63.2	63.2	63.2	70.2	89.5	100.0	100.0
Whit	18000.0	10732.51	41.67	40.37	41.7	41.8	41.8	42.0	42.3	42.4	42.7	3.5	3.5	3.5	19.3	29.8	36.8	68.4
WacoL	80800.0	1548.44	97.37	98.08	97.4	97.4	97.5	97.5	98.0	98.5	99.4	91.2	91.2	93.0	93.0	96.5	100.0	100.0
WacoG	32300.0	4095.71	92.11	87.32	92.1	92.5	92.8	93.4	94.6	95.0	95.2	47.4	52.6	54.4	61.4	73.7	94.7	100.0
High	44800.0	7191.16	90.94	83.95	90.9	91.2	91.7	92.5	93.9	95.3	95.9	45.6	47.4	50.9	52.6	70.2	91.2	100.0
Belton	180260.0	25220.10	82.60	86.01	82.6	83.0	83.0	83.8	84.6	87.7	93.0	56.1	56.1	57.9	61.4	77.2	91.2	100.0
George	25610.0	6512.08	67.69	74.57	67.7	68.4	68.7	70.2	72.7	78.7	92.3	33.3	35.1	38.6	40.4	49.1	77.2	100.0
Grang	42000.0	6892.19	78.51	83.59	78.5	78.7	78.8	80.8	84.6	88.2	93.3	49.1	50.9	50.9	52.6	68.4	89.5	100.0
Camer	209600.0	45717.79	75.29	78.19	75.3	76.2	76.8	79.7	86.3	92.1	99.3	15.8	15.8	17.5	36.8	63.2	87.7	100.0
Bryan	98900.0	7154.18	84.50	92.77	84.5	84.6	85.4	91.2	97.8	99.1	99.6	35.1	40.4	57.9	70.2	94.7	100.0	100.0
Hemp	1119700.0	135862.64	76.17	87.87	76.2	78.8	81.1	86.5	89.2	93.4	99.1	24.6	47.4	57.9	66.7	78.9	94.7	100.0
Total	2106770.0	271711.59		87.10														

SHORTAGE METRICS FOR SELECTED CONTROL POINTS

NAME	MAXIMUM SHORTAGE (AC-FT)	VULNERABILITY (AC-FT/SQ)	RESILIENCY (MONTHS^-1)	AVERAGE SEVERITY (AC-FT/SQ)	SHORTAGE INDEX (MONTHS^-1)	MEAN NUMBER OF FAILURES PER SEQUENCE	MAXIMUM NUMBER OF CONSECUTIVE SHORTAGES (MONTHS)
PK	28896.88	20541.566	0.324	45705.19	2.50	0.49	8
Whit	2124.00	1909.776	0.145	10656.24	49.14	1.14	12
WacoL	9127.19	6106.676	0.323	15969.37	0.55	0.11	5
WacoG	9819.20	5627.487	0.682	6673.52	5.01	0.65	4
High	13619.20	8766.876	0.564	12016.86	6.74	0.63	5
Belton	20805.26	16499.234	0.226	53221.83	6.02	0.49	9
George	2845.56	2286.205	0.182	9224.25	12.41	0.75	10
Grang	4666.67	3938.296	0.209	12718.71	6.98	0.56	11
Camer	40105.78	24203.795	0.366	42380.62	8.45	1.11	9
Bryan	16259.59	5324.401	0.443	8702.95	1.40	0.84	7
Hemp	149963.20	57615.027	0.297	152980.00	4.41	1.04	11

The one in column 28 of the second 2REL record in the TIN file of Table 7.4 activates an optional feature that creates the above auxiliary table of shortage metrics along with the reliability table. Shortage refers to a failure to supply a diversion target during a month of the simulation. The quantities in the shortage metrics table above are defined earlier in this chapter.

The two flow-frequency tables in Table 7.6, created with the *2FRE* records shown in Table 7.4, illustrate the alternative row and column formats. The first regulated flow frequency table in Table 7.6 shows the percentage-of-time or likelihood of monthly flow volumes equaling or exceeding various amounts during the period April through March conditioned upon storage in all reservoirs being at 10% of capacity at the beginning of April. The second table in Table 7.6 shows frequencies for monthly regulated flow volumes during September given the preceding storage conditions at the beginning of April.

Table 7.6
Flow Frequency Tables for CRM Example 7.1 Created with 2FRE Records

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
PK	30394.7	102762.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	25775.	98374.	1782155.
Whit	39857.2	145254.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	3354.	32686.	99523.	2647890.
WacoL	12233.9	40662.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	37843.	526063.
WacoG	78371.4	188220.	0.0	0.0	0.0	110.0	3101.9	11350.0	24815.	34514.	51453.	78964.	141670.	3041216.
High	108087.3	215298.	0.0	0.0	0.0	2069.5	5313.1	22018.8	40050.	54262.	73393.	104020.	223681.	3263993.
Belton	14784.9	45036.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	3682.	39215.	514528.
George	2056.4	6732.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	0.	6192.	65552.
Grang	7900.7	19992.	0.0	0.0	0.0	0.0	0.0	0.0	0.	0.	0.	5204.	25216.	200100.
Camer	66405.3	120124.	0.0	292.7	295.9	305.8	305.8	4868.1	13496.	23696.	40350.	75617.	164339.	1392558.
Bryan	205671.4	353605.	0.0	2781.2	4674.6	7988.3	21379.1	56057.3	82799.	99223.	116020.	210164.	472359.	4246750.
Hemp	241813.5	464915.	9205.5	9205.5	9863.0	9863.0	9863.0	10191.8	10192.	31668.	95217.	294028.	737909.	5187164.

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS FOR MONTH 9

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

CP	PK	Whit	WacoL	WacoG	High	Belton	George	Grang	Camer	Bryan	Hemp
Mean	41563.31	35072.26	2622.20	54602.33	62409.89	9883.34	650.34	2707.92	25703.43	97833.13	55797.08
Std Dev	17585.21	12419.73	3549.23	13461.16	14923.11	6498.34	980.64	2311.29	11771.99	25319.98	40786.48
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2844.91	9863.00
99.5%	0.00	0.00	0.00	0.00	242.26	0.00	0.00	0.00	55.29	3203.68	9863.00
99%	0.00	0.00	0.00	0.00	484.52	0.00	0.00	0.00	110.58	3562.45	9863.01
98%	0.00	0.00	0.00	7.41	990.41	0.00	0.00	0.00	208.26	4206.11	9863.01
95%	0.00	0.00	0.00	725.35	2987.46	0.00	0.00	0.00	295.89	8634.26	9863.01
90%	0.00	0.00	0.00	2669.63	4741.08	0.00	0.00	0.00	295.89	10643.59	9863.01
85%	0.00	0.00	0.00	5174.44	6140.15	0.00	0.00	0.00	295.89	24834.82	9863.01
80%	0.00	0.00	0.00	6587.19	9339.98	0.00	0.00	0.00	344.37	42322.04	9863.01
75%	0.00	0.00	0.00	11420.35	19599.79	0.00	0.00	0.00	935.93	49113.36	9863.01
70%	0.00	0.00	0.00	13279.51	26232.14	0.00	0.00	0.00	1834.68	67344.91	9863.01
60%	0.00	3205.85	0.00	27043.34	42713.64	0.00	0.00	0.00	4197.51	90746.59	9863.01
50%	10174.68	12046.68	0.00	55170.81	55064.08	0.00	0.00	0.00	8034.71	95222.39	9863.01
40%	33846.16	36251.43	0.00	75975.16	78780.34	0.00	0.00	0.00	18252.59	100616.08	9863.02
30%	62986.38	57215.30	0.00	81609.29	86146.20	1856.06	0.00	49.50	31654.77	104089.45	9863.02
25%	87816.70	63080.14	0.00	85986.09	94855.52	7905.04	0.00	184.75	35107.00	110190.91	22880.34
20%	99855.84	86903.79	0.00	95694.99	97837.66	13561.54	0.00	467.80	44399.88	116638.52	47560.34
15%	101723.45	95108.45	0.00	99199.31	100644.62	23650.45	54.45	5033.72	56398.31	133622.19	74308.88
10%	101723.45	95518.31	0.00	108238.95	118047.63	38193.50	106.10	8855.31	83133.06	147592.20	153294.45
5%	120446.76	100366.19	18291.73	153706.52	173834.48	84631.56	3376.43	26965.38	99210.95	298205.12	413412.53
2%	312552.22	181012.41	76556.70	186798.19	229580.25	98012.96	22414.29	41698.97	223902.58	491212.62	839513.50
1%	326553.28	190561.09	81597.80	188336.06	232876.84	99476.24	25001.44	42998.88	240048.84	494561.72	905417.25
0.5%	326553.28	190561.09	81597.80	188336.06	232876.84	99476.24	25001.44	42998.88	240048.84	494561.72	905417.25
Maximum	326553.28	190561.09	81597.80	188336.06	232876.84	99476.24	25001.44	42998.88	240048.84	494561.72	905417.25

Table 7.7
Storage Frequency Tables for CRM Example 7.1 Created with 2FRE Records

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 6

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
RESERVOIR	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	235045.	56177.	0.	0.	0.	0.	0.	70382.	144676.	195344.	267032.	409901.	570240.	570240.
Whit	295037.	51657.	60661.	69959.	78368.	102272.	123273.	141213.	182911.	237135.	284640.	432971.	627100.	627100.
WacoL	109702.	19824.	8686.	9262.	9821.	11126.	18846.	40861.	88730.	104560.	141650.	192100.	192100.	192100.
Belton	177486.	46387.	0.	0.	0.	0.	0.	43840.	79714.	133515.	201991.	278269.	457600.	457600.
George	14891.	4271.	0.	0.	0.	0.	0.	73.	5135.	10405.	15877.	32988.	37100.	37100.
Grang	31417.	7976.	0.	0.	0.	0.	0.	458.	11333.	30712.	42643.	65500.	65500.	65500.
Total	863577.	161065.	74797.	82434.	92500.	123691.	165885.	383978.	604965.	799001.	1030689.	1306886.	1663709.	1949640.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 9

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
RESERVOIR	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	206101.	54605.	0.	0.	0.	0.	0.	4733.	92972.	203326.	257053.	374650.	487601.	570240.
Whit	303148.	46417.	54811.	83531.	106221.	116190.	127551.	170329.	223600.	271681.	366542.	385182.	596580.	627100.
WacoL	100022.	20085.	0.	0.	0.	0.	14263.	29081.	58248.	104159.	145408.	170727.	191505.	192100.
Belton	128921.	42663.	0.	0.	0.	0.	0.	0.	33867.	70288.	120726.	203594.	398549.	457600.
George	6961.	3289.	0.	0.	0.	0.	0.	0.	0.	0.	1723.	12225.	32294.	33169.
Grang	14354.	5882.	0.	0.	0.	0.	0.	0.	242.	2350.	10125.	22251.	59130.	64866.
Total	759506.	151951.	54811.	96648.	128363.	137832.	157613.	233589.	552670.	708487.	923445.	1187755.	1587152.	1934023.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 3

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
RESERVOIR	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	241562.	57092.	0.	0.	0.	0.	0.	50798.	149660.	237853.	300297.	416659.	566660.	570240.
Whit	436773.	44538.	137552.	154264.	167223.	181517.	220889.	316070.	379000.	410974.	497877.	606743.	627100.	627100.
WacoL	136867.	19734.	0.	1157.	2558.	9291.	18771.	87881.	147020.	184543.	192100.	192100.	192100.	192100.
Belton	204597.	51774.	0.	0.	0.	0.	0.	32147.	109170.	174518.	243638.	437178.	457600.	457600.
George	16411.	4562.	0.	0.	0.	0.	0.	0.	4208.	13526.	24134.	37100.	37100.	37100.
Grang	37112.	8274.	0.	0.	0.	0.	0.	5223.	20190.	54414.	62908.	65500.	65500.	65500.
Total	1073321.	164013.	148393.	166002.	182688.	223624.	354062.	578166.	885140.	1076106.	1295203.	1568541.	1913892.	1949640.

Table 7.8
Frequency Table for CRM Example 7.1 Created with 2FRQ Record

STORAGE-FREQUENCY FOR RESERVOIR Belton FOR MONTH 3

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

STORAGE	FREQ(%)	STORAGE	FREQ(%)	STORAGE	FREQ(%)	STORAGE	FREQ(%)	STORAGE	FREQ(%)
50000.0	70.18	100000.0	61.40	200000.0	45.61	400000.0	28.07	450000.0	22.81

Table 7.9
Reservoir Storage Table for CRM Example 7.1 Created with 2RES Records

RESERVOIR STORAGE DRAWDOWN DURATION FOR MONTH 6

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

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	235044.66	0.	570240.	57.	49.	49.	48.	44.	37.	23.	13.	8.
Whit	295036.50	379000.	627100.	57.	51.	51.	51.	49.	45.	44.	42.	40.
WacoL	109701.16	580.	192100.	57.	40.	40.	39.	36.	25.	17.	6.	0.
Belton	177485.30	0.	457600.	57.	50.	47.	46.	45.	37.	26.	16.	8.
George	14891.12	240.	37100.	57.	46.	45.	43.	41.	37.	27.	22.	15.
Grang	31416.70	220.	65500.	57.	40.	40.	39.	36.	29.	25.	19.	14.

RESERVOIR STORAGE RELIABILITY FOR MONTH 6

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

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	235044.66	0.	570240.	12.3	14.0	14.0	15.8	22.8	35.1	59.6	77.2	100.0
Whit	295036.50	379000.	627100.	10.5	10.5	10.5	10.5	14.0	21.1	22.8	26.3	36.8
WacoL	109701.16	580.	192100.	26.3	29.8	29.8	31.6	36.8	56.1	70.2	89.5	100.0
Belton	177485.30	0.	457600.	12.3	12.3	17.5	19.3	21.1	35.1	54.4	71.9	100.0
George	14891.12	240.	37100.	17.5	19.3	21.1	24.6	28.1	35.1	52.6	61.4	73.7
Grang	31416.70	220.	65500.	29.8	29.8	29.8	31.6	36.8	49.1	56.1	66.7	75.4

Table 7.9 (Continued)
Reservoir Storage Table for CRM Example 7.1 Created with 2RES Records

RESERVOIR STORAGE DRAWDOWN DURATION FOR MONTH 9

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

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	206100.70	0.	570240.	57.	53.	53.	53.	47.	39.	27.	19.	15.
Whit	303147.66	379000.	627100.	57.	54.	54.	52.	51.	48.	46.	45.	43.
WacoL	100021.91	580.	192100.	57.	51.	47.	45.	34.	26.	19.	10.	4.
Belton	128920.44	0.	457600.	57.	54.	54.	53.	50.	44.	33.	25.	18.
George	6960.28	240.	37100.	57.	57.	57.	57.	50.	47.	42.	40.	31.
Grang	14353.23	220.	65500.	57.	55.	55.	52.	50.	48.	40.	31.	23.

RESERVOIR STORAGE RELIABILITY FOR MONTH 9

CONDITIONAL RELIABILITY MODELING: Equal-Weight Option
Annual cycles starting in month 4
Length of simulation period (CR1) is 12 months.
Initial storage multiplier (CR4) = 0.100

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	206100.70	0.	570240.	5.3	7.0	7.0	7.0	17.5	31.6	52.6	66.7	100.0
Whit	303147.66	379000.	627100.	5.3	5.3	5.3	8.8	10.5	15.8	19.3	21.1	35.1
WacoL	100021.91	580.	192100.	7.0	10.5	17.5	21.1	40.4	54.4	66.7	82.5	93.0
Belton	128920.44	0.	457600.	5.3	5.3	5.3	7.0	12.3	22.8	42.1	56.1	100.0
George	6960.28	240.	37100.	0.0	0.0	0.0	0.0	12.3	17.5	26.3	29.8	45.6
Grang	14353.23	220.	65500.	0.0	3.5	3.5	8.8	12.3	15.8	29.8	45.6	59.6

Table 7.7 presents end-of-month reservoir storage frequency tables for June, September, and March (months 6, 9, and 3). The exceedance frequency estimates reflect given storage levels at the beginning of April in all reservoirs equal to 10% of their storage capacity. There is a 25% probability that the end-of-June storage contents of Belton Reservoir will equal or exceed 278,269 acre-feet given that the storage contents at the beginning of April is 45,760 acre-feet. For Belton Reservoir, Table 7.7 indicates a 25% probability that the storage at the end of September will equal or exceed 203,594 acre-feet or at the end of March will equal or exceed 437,178 acre-feet conditioned upon the preceding beginning-of-April storage of 45,760 ac-ft.

The frequency table in Table 7.8 reproduced from the *TABLES* output TOU file was created in accordance with the *2FRQ* record shown in Table 7.4. The frequency relationship is for end-of-month storage for March (month 3) in Belton Reservoir given that storage 12 months earlier at the beginning of April was at 10% of the reservoir capacity for all six reservoirs including Belton. Given that storage in Belton Reservoir is at 10% of its capacity of 457,600 acre-feet at the beginning of April, there is an estimated probability of 0.7018 that the storage volume will be at least 50,000 acre-feet twelve months later and probability of 0.2281 that the storage will equal or exceed 450,000 ac-ft twelve months later.

The *2RES* records create the storage drawdown and storage reliability tables shown in Table 7.9. The storage reliability table for June (month 6) shows that with PK Reservoir having a storage content of 10% of its capacity at the beginning of April, there is an estimated 12.3% frequency, probability, or likelihood that PK Reservoir will be 100% full to capacity at the end of June and a 35.1% probability that the end-of-June storage content will be at least 50% of capacity. The table shows a 77.2% percentage-of-time or probability of PK Reservoir having an end-of-June storage volume of at least 10% of storage capacity given that the preceding beginning-of-April storage is 10% of capacity.

The storage table for Granger Reservoir shown in Table 7.10 was created with a *2STO* record. Each row represents one simulation sequence. The UNIT record is included in the TIN file of Table 7.4 so that the Table 7.10 table headings will begin with April rather than January.

Hundreds of tables may be generated to provide an array of information of interest in a particular decision-support situation. Tables 7.4 through 7.10 provide a small illustrative sampling of alternative contents and formats of reliability and frequency tables. *2STO* and similar time series records also write any of the *SIM* simulation results time series data as HEC-DSS records for plotting with HEC-DSSVue.

The tables in Tables 7.5, 7.6, 7.7, 7.8, 7.9, and 7.10 are from a single *TABLES* output TOU file. The computations performed by program *TABLES* for conditional reliability modeling (CRM) with the equal-weight option based on *SIM* simulation results from a CRM file are the same as conventional WRAP applications using simulation results from an OUT file. The format of the tables is also the same with either CRM or conventional applications except for the four lines added to the header that define CRM specifications from the *CR* record.

Since a CR1 of 12 months is specified on the *CR* record, 2REL, 2FRE, 2FRQ, and 2RES tables can be constructed for the aggregate of all months or for either individual month of the 12 months of the year. However, in general, tables can be developed only for the months included in the simulation sequence defined by CR1 and CR2. For example, if a simulation length CR1 of 5 months is combined with a starting month of April (CR2=4) in the *SIM* simulation, tables can be constructed by *TABLES* for only April, May, June, July, August, and September. In this case, the number of simulation sequences would be 58 rather than 57.

Each row of storage volumes in the 2STO record table of Table 7.10 represents a simulation sequence. Since CR1 is 12, end-of month storage volumes are tabulated in Table 7.10 for all 12 months of the year. If CR1 is less than 12, only those months included in the simulation sequences are tabulated in 2STO storage tables. The UNIT record allows user specification of the beginning month in the table heading.

Table 7.10
Reservoir Storage Table for CRM Example 7.1 Created with 2STO Record

END-OF-MONTH STORAGE (AC-FT) FOR RESERVOIR Grang

SEQ	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	MEAN
1	13488.0	21221.7	335.9	34106.7	32565.8	29736.0	20265.2	65500.0	65500.0	65500.0	65500.0	65500.0	39934.9
2	61797.6	65500.0	65500.0	65500.0	63383.6	60797.8	64557.2	63627.3	63653.0	63009.9	62004.6	60403.2	63311.2
3	27431.6	35616.8	60411.3	58086.8	54434.3	61539.5	65500.0	65500.0	65500.0	65500.0	65500.0	65500.0	57543.4
4	7386.9	8647.8	6075.9	0.0	0.0	0.0	0.0	0.0	0.0	8938.2	32333.8	63108.4	10540.9
5	19165.3	65500.0	65500.0	63538.3	0.0	3999.1	2232.1	5867.1	26791.5	59625.4	65500.0	65500.0	36934.9
6	46644.2	61793.9	65500.0	65500.0	59570.3	58546.8	58883.9	61149.6	62100.6	65500.0	65500.0	65500.0	61349.1
7	19108.7	34725.0	37979.7	25222.2	11852.9	9549.4	13380.9	32228.6	59849.2	65500.0	65500.0	65500.0	36699.7
8	19106.7	24753.8	24190.3	11548.5	9548.1	1077.8	0.0	0.0	0.0	0.0	0.0	0.0	7518.8
9	18535.9	32291.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1160.0	4332.3
10	21502.4	22799.9	25091.5	22824.6	18798.5	15649.5	13223.6	10034.1	8180.5	6252.9	7209.6	5869.4	14786.4
11	7646.2	10846.5	10882.3	8052.9	3542.4	302.0	0.0	0.0	0.0	0.0	0.0	0.0	3439.3
12	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
13	15530.7	31001.0	10911.1	0.0	0.0	0.0	0.0	0.0	11933.2	13705.1	15520.7	17333.7	9661.3
14	0.0	15321.9	13332.1	0.0	0.0	1209.4	18689.6	19490.4	20500.2	20439.5	17615.7	10290.0	11407.4
15	4335.5	2574.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	575.8
16	4748.7	13939.1	16750.9	13320.8	10791.0	7455.2	3520.9	419.1	0.0	0.0	0.0	0.0	5912.1
17	0.0	1327.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.5	111.9
18	65500.0	65500.0	65500.0	64448.4	60568.5	60490.0	65500.0	65500.0	65500.0	65500.0	65500.0	65500.0	64583.9
19	18020.8	32520.8	36333.0	26026.3	23978.2	27942.7	29196.9	30406.8	31447.5	7290.4	9611.2	11434.9	23684.1
20	12501.5	15240.5	9879.4	8610.9	707.2	0.0	65500.0	65500.0	65500.0	65500.0	65500.0	65500.0	36661.6
21	14090.7	16524.9	7521.5	0.0	0.0	0.0	15784.7	27249.9	64640.2	65500.0	65500.0	65500.0	28526.0
22	13110.3	0.0	823.4	12397.4	12893.2	15199.2	17276.8	19315.2	21726.9	23471.2	24831.7	25269.1	15526.2
23	0.0	2925.4	6726.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	804.3
24	5698.4	4197.0	62.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1387.2	5007.6	1362.7
25	8675.0	0.0	0.0	0.0	0.0	1673.0	321.7	5282.9	7214.1	14131.7	46796.8	62857.6	12246.1
26	18289.7	65500.0	65500.0	65500.0	0.0	9662.0	12568.1	23451.4	44816.1	56358.2	65500.0	65500.0	41053.8
27	54009.5	65500.0	57374.4	45457.2	0.0	9999.5	10439.9	10147.1	10538.0	10222.2	10051.3	9179.2	24409.9
28	7885.7	23347.0	11438.3	0.0	0.0	0.0	0.0	9260.2	18742.6	65500.0	65500.0	65500.0	22264.5
29	28069.6	63777.9	65500.0	65500.0	54443.0	57958.9	57551.5	61100.3	65500.0	65500.0	65500.0	65500.0	59658.4
30	40569.8	65500.0	65500.0	53444.6	0.0	2051.6	3862.3	4360.6	10052.6	16940.2	35117.4	65500.0	30241.6
31	23627.1	54693.2	49564.9	0.0	0.0	2648.6	2352.2	1733.3	0.0	0.0	0.0	0.0	11218.3
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5800.6	13457.8	15965.0	17238.6	17133.6	5799.6
33	0.0	4704.1	0.0	0.0	0.0	0.0	0.0	9448.8	14408.0	26462.0	41312.2	56000.9	12694.7
34	30387.2	59503.7	65500.0	43561.2	3036.0	11774.5	62808.9	65500.0	65500.0	65500.0	65500.0	65500.0	50339.3
35	9421.1	36896.2	0.0	0.0	0.0	16089.7	23631.3	65500.0	65500.0	65500.0	65500.0	65500.0	34461.5
36	13383.0	64695.1	65500.0	65500.0	44032.8	1398.3	1076.8	989.7	1205.3	1153.4	679.1	679.5	21691.1
37	35974.0	65500.0	65500.0	65500.0	0.0	0.0	1574.1	5457.1	18053.9	26958.3	51901.5	62328.3	33228.9
38	56893.3	65500.0	65500.0	52698.7	37130.4	0.0	0.0	0.0	0.0	0.0	1034.4	904.4	23305.1
39	7021.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9055.5	32675.0	65500.0	9521.0
40	39876.3	65500.0	65500.0	65500.0	65500.0	64866.2	54302.4	41468.3	42517.3	42328.6	48804.7	53002.3	54097.2
41	9696.7	24909.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	998.9	6406.6	3500.9
42	10267.2	19738.7	65500.0	65500.0	0.0	22337.2	40345.6	49020.1	52248.7	53929.8	54608.8	55826.1	40776.8
43	14384.1	40027.1	47046.7	35860.5	23016.6	10626.5	7952.1	7010.3	6755.0	7604.3	14644.5	31384.8	20526.0
44	12179.8	44690.4	57905.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9564.6
45	2712.1	0.0	0.0	0.0	0.0	0.0	29218.9	34441.1	46312.8	57005.9	65500.0	65500.0	25057.6
46	20678.5	34268.6	38152.5	26416.8	12640.3	0.0	5859.6	19608.7	47803.5	55964.9	65500.0	65500.0	32699.5
47	0.0	6095.9	22382.8	20480.7	17299.5	17324.9	36262.5	45277.0	65500.0	65500.0	65500.0	65500.0	35593.6
48	14793.3	47186.3	65500.0	65500.0	23030.7	23645.4	23112.8	29466.7	34577.8	38465.6	40500.5	41970.0	37312.4
49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	941.5	78.5
50	6303.5	38740.6	41542.4	28363.9	24482.1	20636.3	18023.9	15883.4	13738.2	12176.8	10961.5	15384.7	20519.8
51	11278.0	40919.4	37160.2	31715.4	26129.8	21994.2	18030.6	15612.7	13077.9	31610.8	42233.7	48169.3	28161.0
52	46477.0	65500.0	65500.0	53050.9	41293.9	41775.1	41956.6	42479.8	65500.0	65500.0	65500.0	65500.0	55002.8
53	22445.9	65500.0	65500.0	65500.0	65500.0	64355.6	63172.8	64885.8	65500.0	65500.0	65500.0	65500.0	61571.7
54	24133.0	56438.8	65500.0	65500.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17631.0
55	5232.3	9256.3	6612.5	2107.1	0.0	0.0	7898.2	9565.5	27323.0	37207.0	41155.4	56908.3	16938.8
56	14027.2	30162.9	40777.1	38808.3	37612.5	34697.4	31347.1	29094.4	27250.4	25223.4	23657.1	20904.1	29463.5
57	5085.0	0.0	0.0	0.0	0.0	29142.4	0.0	1254.7	18425.6	27957.2	54526.9	65500.0	16824.3
MEAN	17704.0	31733.7	31416.9	26327.2	14697.9	14353.5	17669.9	21138.4	26216.5	29586.9	33656.4	37111.8	25134.4

Table 7.11 below illustrates a convenient format for presenting a CRM storage-frequency relationship for a particular reservoir. The storage-frequency relationship for Granger Reservoir presented in Table 7.11 was compiled from twelve 2FRE tables which include the frequency tables for June, September, and March (months 6, 9, 12) reproduced in Table 7.7 and additional 2FRE tables for each of the other nine months. The twelve 2FRE tables are derived from the results of a single *SIM* simulation. Program *TABLES* computed the statistics in Table 7.11 from the 57 storage volumes for each of the 12 months of the year that are tabulated in Table 7.10.

Table 7.11
Storage-Frequency Relationships for Granger Reservoir for
Initial Storage Volume of 10 Percent of Capacity at the Beginning of April

Month	4 Apr	5 May	6 Jun	7 Jul	8 Aug	9 Sep	10 Oct	11 Nov	12 Dec	1 Jan	2 Feb	3 Mar
Mean	18,144	32,048	31,417	26,568	14,853	14,354	17,829	21,297	26,217	29,587	33,656	37,112
St Dev	4,602	6,971	7,976	7,723	6,088	5,882	6,470	6,947	7,453	7,759	7,889	8,274
100%	0	0	0	0	0	0	0	0	0	0	0	0
99%	0	0	0	0	0	0	0	0	0	0	0	0
98%	0	0	0	0	0	0	0	0	0	0	0	0
95%	0	0	0	0	0	0	0	0	0	0	0	0
90%	3,848	0	0	0	0	0	0	0	0	0	0	0
75%	7,452	10,994	458	0	0	0	0	0	0	288	1,123	0
60%	11,076	22,484	11,333	7,389	0	242	2,100	5,732	11,654	13,399	17,540	5,223
50%	13,758	31,646	30,712	24,023	0	2,350	7,925	9,800	18,240	24,347	37,809	20,190
40%	18,075	37,265	42,643	32,194	11,003	10,125	16,083	19,514	27,265	37,459	49,424	54,414
25%	23,332	61,221	65,500	56,926	25,717	22,251	29,213	39,712	57,949	64,877	65,500	62,908
10%	46,527	65,500	65,500	65,500	55,981	59,130	62,918	65,500	65,500	65,500	65,500	65,500
Max	65,500	65,500	65,500	65,500	65,500	64,866	65,500	65,500	65,500	65,500	65,500	65,500

End-of-month storage volumes in acre-feet in Granger Reservoir are tabulated for each of 12 months of the year in Table 7.11 from the results of a *SIM* simulation with the beginning-of-April storage contents set at 10 percent of capacity in each of the six reservoirs. The capacity of Granger Reservoir is 65,500 acre-feet. The interpretation of the CRM storage-frequency relationship of Table 7.11 is illustrated as follows.

The June column of Table 7.11 refers to the 57 end-of-June storage volumes tabulated in Table 7.10. The mean and standard deviation of the 57 volumes are 31,417 and 7,976 acre-feet. Granger Reservoir is at its full capacity of 65,500 ac-ft at the end of June for between 25% and 40% of the 57 simulation sequences. The end-of-June storage volume equals or exceeds 30,712 ac-ft in 50 percent of the 57 simulation sequences. Thus, the estimated probability of the storage level being at or above 30,712 ac-ft at the end of June is 50 percent if the storage content is 6,550 ac-ft at the beginning of April. The corresponding median or 50 percent exceedance frequency storage contents for the end of September and March are 2,350 and 20,190 acre-feet. There is a 60% likelihood that the Granger Reservoir storage contents will equal or exceed 242 ac-ft at the end of September if the storage volume is 10% of capacity at the beginning of April.

Options for Assigning Probabilities to the Simulation Sequences

Two alternative strategies may be adopted for assigning probabilities to each of the short-term hydrologic simulation sequences.

equal-weight option− Frequencies and reliabilities are estimated based on simply treating each simulation sequence as one possibility out of the total number of simulation sequences. Preceding storage is not explicitly considered in assigning probabilities to sequences.

probability array option− Preceding storage contents is considered in assigning probabilities to each of the individual simulation sequences using techniques outlined by the remainder of this chapter.

The preceding example illustrates the default equal-weight approach. The 57 alternative simulations are each weighted the same in the frequency and reliability computations. Each of the 57 twelve-month long sequences of naturalized flows and net evaporation rates represent one possible occurrence of hydrologic conditions. Each sequence is implicitly assigned a weight of 1/57 in the frequency and reliability counts. Some sequences have extremely low or extremely high flow volumes and net evaporation rates, representing infrequent drought or flooding conditions, while other sequences reflect more normal hydrologic conditions. Relatively few of the hydrologic sequences reflect infrequent extremes. Many more sequences are representative of more normal conditions that occur the majority of the time. The probabilistic nature of river basin hydrology is captured by the frequency of occurrence of the range from low to high natural stream flows and net reservoir evaporation less precipitation rates. The 57 hydrologic simulation sequences provide a sample of 57 occurrences which are adopted as being representative of the frequency characteristics of the continually varying hydrologic conditions in the river basin.

In the preceding Example 7.1, the hydrology represented by each sequence is not treated as being equally likely, but the sequences are equally-weighted in the sense of each being counted once. The CRM approach of simply applying Eqs. 7.2−7.7 with each of the N simulation sequences considered one time is called the *equal-weight option*. In the *probability array option* outlined by the remainder of this section, each sequence is explicitly assigned both an exceedance probability and incremental probability as a function of preceding storage that vary between sequences. The summation of the incremental probabilities total to 1.0.

The computational procedures activated by the *TABLES 2REL*, *2FRE*, *2FRQ*, and *2RES* records provide reliability and frequency estimates based on Equations 7.2, 7.3, and 7.4. The *2FRE* record options for applying the normal or log-normal probability distributions may be applied with conventional non-CRM applications or with either the CRM equal-weight option or probability array option. The equal-weight option provides valid estimates of frequencies and reliabilities and may often be the best choice for particular CRM applications. However, improvements in accuracy of the frequency and reliability estimates may be achieved in some applications by selected sets of other *TABLES* options that are based on more sophisticated computational methods for assigning probabilities to each of the multiple simulation sequences. These more complex options are based on the concept that the likelihood of the hydrologic sequences may be correlated to various degrees with preceding reservoir storage levels.

The remainder of this chapter outlines sets of computational options incorporated in *TABLES* for assigning probabilities to each of the multiple hydrologic sequences. The *SIM* CRM simulation is not affected by these methods for assigning probabilities to the *SIM* generated simulation sequences. Likewise, the general format of the tables in the TOU file generated by *TABLES* is not affected.

<u>Alternative Probability Estimation Strategies</u>

Reliability and frequency estimates vary depending on the approach adopted in *TABLES* for assigning probabilities to each of the multiple hydrologic sequences of naturalized flows and net evaporation-precipitation depths generated by the *SIM/SIMD* simulation. *TABLES* provides alternative options for various tasks associated with assigning probabilities to each of the multiple CRM simulation sequences. The alternative strategies are outlined as follows.

1. The *equal-weight option* is based on weighting each of the hydrologic sequences the same in applying the basic relative frequency concepts expressed in Equations 7.2, 7.3, 7.4, 7.5, 7.6, and 7.7.

2. The *probability array option* allows probabilities to be assigned to each hydrologic sequence with alternative sets of methods designed to consider preceding storage contents. However, preceding storage may still be ignored with option 2a below.

    a. The *flow-frequency (FF) relationship option* is based on assigning exceedance probabilities directly to naturalized flow volumes using either the log-normal probability distribution or Weibull formula. Preceding reservoir storage may be either incorporated into the determination of probability distribution parameters by using only sequences with preceding storage falling within a specified range or simply ignored.

    b. The *storage-flow-frequency (SFF) relationship option* is based on probabilistically representing deviations in naturalized flow volumes from the amounts indicated by a regression relationship between preceding reservoir storage volume and naturalized stream flow volume.

The equal-weight option involves no special features in *TABLES*. The computations associated with the *2REL*, *2FRE*, *2FRQ*, and *2RES* records and Eqs. 2.2−2.7 are the same for a conditional reliability modeling (CRM) application with the equal-weight option and a conventional non-CRM application. The *2FRE* record also includes an option that allows use of a probability distribution function for use with either CRM or non-CRM applications. This generic *2FRE* record probability distribution option is separate from the CRM probability array option described below and may be applied in combination with the CRM equal-weight option.

The probability array option also uses the same computational routines associated with the *2REL*, *2FRE*, *2FRQ*, and *2RES* input records but incorporates an exceedance probability (FF or SFF) relationship used to assign an incremental probability to each simulation sequence. These incremental probabilities vary between sequences and sum to 1.0. If the incremental probability (IP) array happens to contain equal probabilities for all sequences, the probability array and equal-weight options yield the same reliability and frequency analysis results.

The CRM probability array option assigns probabilities to each of the hydrologic sequences. Either a flow-frequency (FF) or storage-flow-frequency (SFF) relationship is developed for use in developing the incremental probability (IP) array. The SFF relationship option incorporates preceding reservoir storage in more detail in assigning of flow probabilities. With the probability distribution option for performing CRM reliability and frequency analyses, an array assigning a probability to each of the hydrologic sequences produced in the *SIM/SIMD* simulation is developed by *TABLES* in two steps.

1. A FF or SFF relationship is developed from sequences of monthly naturalized flow volume and preceding storage volume read from a *SIM/SIMD* output file for a conventional single long-term *SIM/SIMD* simulation as specified by a *5CR1* record.
2. The array of naturalized flow volumes for each simulation sequence read from a CRM execution of *SIM/SIMD* for a given initial storage condition is combined with the FF/SFF relationship of step 1 above to develop an array of incremental probabilities (IP array) for the hydrologic sequences as specified by a *5CR2* record.

The *5CR1* record controls development of a flow-frequency (FF) or storage-flow-frequency (SFF) relationship from a single conventional long-term *SIM/SIMD* simulation using either annual or monthly (non-annual) cycles to define flow segments. The *5CR2* record develops an array assigning an incremental probability (IP) to each simulation sequence of a CRM analysis. The FF or SFF relationship developed by the *5CR1* record is used in the routines controlled by the *5CR2* record to develop the IP array.

The model-user may specify lower and upper limits defining a reservoir storage range on the *5CR1* record. Only those naturalized flow sequences with the preceding storage falling within the specified range are used in building the FF or SFF relationship. For example, assume that a CRM analysis is being performed for an initial storage content of 50 percent of the storage capacity. The model-user may choose to build the FF or SFF relationship using only flow sequences that follow storage contents falling in the range of 20 to 80 percent of capacity. For the FF option, the storage limits provide the only mechanism for relating naturalized flow volume to preceding storage. The FF option may also be applied without specifying storage limits and thus without relating naturalized flow volume to preceding storage.

Relationship between Naturalized Stream Flow and Preceding Reservoir Storage

The SFF option for assigning probabilities to each of the multiple simulation sequences as a function of preceding reservoir storage pivots around the storage-flow-frequency (SFF) relationship. The SFF relationship relates exceedance probabilities to the random variable $Q_{\%}$.

$$Q_{\%} = \frac{Q}{Q_S}\ 100\% \tag{7.8}$$

where Q is the naturalized flow volume over one or more months observed in the *SIM/SIMD* CRM simulation results, and Q_S is the corresponding expected value of the naturalized flow volume determined from a regression equation reflecting preceding storage volume. The naturalized flow volume is the total summed for the months specified by the parameter FM on the *5CR1* record which defaults to the CR1 months from the *CR* record.

The flow $Q_{\%}$ is the naturalized flow volume observed in the model as a percentage of the flow volume expected from relating flow to preceding storage. The magnitude of $Q_{\%}$ expresses the deviation of the flow volume from the expected value of the flow volume conditioned on preceding storage volume as modeled by a regression equation.

Regression Methods

The following exponential (Eq. 7.9), power (Eq. 7.10), linear (Eq. 7.11), and combined (Eq. 7.12) forms of regression equations may be used to relate the naturalized flow volume Q_S in Eq. 7.8 to preceding storage volume S.

$$Q_S = a \times e^{S/b} \tag{7.9}$$

$$Q_S = b\,S^c \tag{7.10}$$

$$Q_S = a + b\,S \tag{7.11}$$

$$Q_S = a + bS^c \tag{7.12}$$

Eq. 7.9 is the default option, where e is the base of the natural logarithms. The parameters a, b, and c are determined by applying least-squares regression to the naturalized flow volumes and preceding reservoir storage volumes from a long-term *SIM* simulation. An option allows forcing the y-intercept to be zero (a=0) for Eqs. 7.11 and 7.12. If the coefficient c is 1.0, Eq. 7.12 reduces to Eq. 7.11. With a value for c other than 1 and a coefficient a of zero, Eq. 7.12 reduces to Eq. 7.10.

A 828-month 1940-2008 simulation comparing a 3-month naturalized flow volume to the preceding storage volume will have either 68 or 69 (annual option) or 825 (monthly option) pairs of values of S_i and Q_i. The storage S_i is the volume content of one or more specified reservoirs at the beginning of each 3-month sequence. The flow Q_i is the total volume of the naturalized stream flow at one or more control points over each 3-month sequence. Application of regression analysis to the pairs of S_i and Q_i results in the parameters a, b, and c for the alternative Eqs. 7.9, 7.10, 7.11, or 7.12.

Standard least-squares linear regression methods outlined in statistics and numerical methods textbooks are used.

$$E(Y\,|\,x) = a + bx \tag{7.13}$$

$$b = \frac{n\Sigma x_i y_i - (\Sigma x_i)(\Sigma y_i)}{n\Sigma x_i^2 - (\Sigma x_i)^2} \tag{7.14}$$

$$a = \bar{y} - b\,\bar{x} \tag{7.15}$$

$E(Y\,|\,x)$ denotes the conditional expectation of Y given x, and $\bar{y}$ and $\bar{x}$ are the means of y and x. Eqs. 7.13, 7.14, and 7.15 are applied with x = S and y = Q to determine values for the coefficients a and b in Eq. 7.11, which represent the y-intercept and slope of a straight line plot.

The linear regression equations (Eqs. 7.13−7.15) are applied to transformed variables to obtain the coefficients a, b, and c for Eq. 7.9 and Eq. 7.10. For the exponential model of Eq. 7.9, the natural logarithm of Q_S is regressed with S, with resulting the y-intercept and slope of a straight line plot being represented by ln a and b, respectively. For the power function of Eq. 7.10, the logarithm of Q_S is regressed with log S, with the resulting y-intercept and slope of a straight line plot being represented by log b and c, respectively. The coefficients b and c for Eq. 7.12 are set in two steps. The exponent c in Eq. 7.12 is fixed based on the power function regression, and then S^c and Q are regressed to obtain the coefficients a and b.

Correlation Coefficients

The correlation coefficient r is the square root of the coefficient of determination r^2.

$$r = \sqrt{r^2} \tag{7.16}$$

The standard linear correlation coefficient r is computed as Eq. 7.17.

$$r = \frac{n\Sigma x_i y_i - (\Sigma x_i)(\Sigma y_i)}{\sqrt{n\Sigma x_i^2 - (\Sigma x_i)^2}\sqrt{n\Sigma y_i^2 - (\Sigma y_i)^2}} \tag{7.17}$$

The linear correlation coefficient is an index of the goodness-of-fit of the regression relationships. The *5CR1* record results in computation of the regression coefficient r from Eq. 7.17 along with the regression coefficients a, b, c of Equations. 7.9−7.15 for the selected regression equation. While Eq. 7.11 is based on a linear relationship between S and Q_S, Eqs. 7.9, 7.10, and 7.12 are based on a linear relationship between variables that are nonlinear functions of S and Q_S. The linear correlation coefficient of Eq. 7.17 is an index of the linear correlation between the previously noted transformed variables.

5CR1 record field 14 activates an option to write a table of statistics to the TOU file that includes the regression and correlation coefficients. The *5COR* record creates the same table without the coefficients for the regression analysis. The *5COR* record allows correlation analyses of storage versus naturalized flow volumes to be performed without activating the other features of the *5CR1* record. The same correlation analysis is included as a *5CR1* record option.

The Spearman rank correlation coefficient for storage versus flow volume is included in the *5COR* and *5CR1* record statistics table as supplemental information. The rank correlation coefficient does not depend upon the actual values of x and y (Q_S and S) but rather their relative rank. The ranks of the two variables in the paired data set are correlated rather than the actual magnitudes. For a set of paired data, (x_i, y_i), i = 1, 2, ... , n, the x_i and y_i are ranked separately with the highest value having rank 1 and the lowest value rank n. The ranks are correlated with Eq. 7.17, which may be algebraically converted to Eq. 7.18. In correlating ranks, the rank correlation coefficient r_r is expressed as Eq. 7.18 where d_i is the difference between the ranks assigned to x_i and y_i for each of the n pairs of values.

$$r_r = \frac{6\Sigma d_i^2}{n(n^2 - 1)} \tag{7.18}$$

The correlation coefficient r provides a measure of the degree of linear correlation between the variables x and y. The rank correlation coefficient r_r provides a measure of the degree of linear correlation between the ranks of the variables x and y. Values of the correlation coefficient can range between –1.0 and 1.0.

$$-1.0 \leq r \leq 1.0 \quad \text{and} \quad -1.0 \leq r_r \leq 1.0$$

A value for r of 1.0 indicates a perfect linear correlation. A plot of x versus y would be a perfect straight line, increasing with increasing magnitudes of x and y. A value for r of –1.0 indicates that x and y are inversely correlated with y decreasing with increasing x. A value for r of 0.0 indicates no linear correlation between x and y. With r near zero, a plot of x versus y would show either random scatter or a highly nonlinear relationship.

The *5COR* correlation coefficient record may be used to compute the correlation coefficient of the sum of naturalized flows at specified control points and reservoir storage at specified reservoirs or control points, without actually developing the *5CR1* record *SFF* or *FF* relationship. The *5COR* record is designed primarily as an aid in determining whether the correlation of flow volume to preceding storage is strong enough to warrant adoption of the storage-flow-frequency (SFF) option and in selection of the control points and reservoirs to be used in developing SFF relationships. A graphical comparison external to WRAP will typically be combined with the correlation coefficients.

Probability Distributions

The exceedance probability is the estimated probability of equaling or exceeding particular values of the random variable X. Restating in terms of frequency, the exceedance frequency is the relative frequency of equaling or exceeding particular values of X. In developing a FF relation, the random variable X is the naturalized flow volume for a specified length of time. In developing a SFF relation, the random variable X is the $Q_{\%}$ defined by Eq. 7.8. The naturalized flow volumes are the sum of the monthly amounts during the period of months specified by the parameter FM on the *5CR1* record which is equivalent to CR1 on the *CR* record. The *TABLES 5CR1* record activates two alternative options for computing exceedance probabilities that are based on either the log-normal probability distribution or Weibull formula.

The first option for modeling the probability distribution of X representing either naturalized flow volumes for a FF relationship or $Q_{\%}$ for a SFF relationship is to apply the log-normal probability distribution using Eq. 7.19 with z derived from the normal distribution.

$$\log X = \overline{\log X} + z\, S_{\log X} \tag{7.19}$$

The mean $\overline{\log X}$ and standard deviation $S_{\log X}$ of the logarithms of X are computed. The frequency factor z is entered by linear interpolation into a normal probability table built into *TABLES* to obtain cumulative probability (1-P) which is converted to exceedance probability (P).

Naturalized stream flow ranges upward from a lower limit of zero, with no defined upper limit. Likewise, the Eq. 7.8 ratio $Q_{\%}$, representing deviations, has a lower limit of zero and no upper limit. The log-normal models the skewed distribution for these types of random variables.

The other option for assigning exceedance probabilities for a SFF or FF relationship involves ranking the flow (Q or $Q_{\%}$) series and applying the Weibull formula:

$$P = \frac{m}{N+1} \tag{7.20}$$

where P denotes exceedance probability, m is the rank of the values (m = 1, 2, 3, ... ,N), and N is the total number of sample values of the random variable. The flow sequence with the greatest flow ratio $Q_{\%}$ or flow volume is assigned a rank of 1, and the smallest is assigned a rank of N. The Weibull relative frequency formula weights each flow sequence (and associated flow volume or Eq. 7.8 flow percentage $Q_{\%}$) equally in developing the SFF or FF relationship. The algorithm in *TABLES* extends the SFF or FF relationship by assigning an exceedance probability of 1.0 to a flow of zero. If a flow volume in a *5CR2* record application exceeds the highest flow included in the *5CR1* record FF or SFF array, the relation is linearly extrapolated using the highest two flows, subject to the limiting restriction that the probability can not be less than zero.

The probability option with a FF relationship developed using the Weibull formula is conceptually similar to the equal-weight option. The computational algorithms differ. The Weibull formula (Eq. 7.20) is applied explicitly to flow volumes at one or more specified control points. Eq. 7.20 can be compared with Eqs. 7.2 and 7.4 upon which the equal-weight option is based. In either case, the concept of relative frequency is applied with each of N sample hydrologic sequences treated as being equally-weighted. Each simulation is assigned the same incremental probability. Relatively few sequences reflect infrequent extremely wet or dry conditions. A larger number of sequences reflect more normal flow conditions that are expected to occur more often. Thus, the computational methods model the probability distribution of stream flow volumes representing hydrologic conditions.

The accuracy of probability estimates based on direct application of relative frequency concepts reflected in Eqs. 7.2, 7.4, and 7.20 is limited by the sample size set by the number of hydrologic sequences. The log-normal probability distribution may improve modeling accuracy by providing a general form for the probability distribution considered representative of either stream flow volumes or the Eq. 7.8 flow $Q_{\%}$ as a percentage of predicted Q representing deviations from the flow volumes indicated by regression with preceding storage.

Flow-Frequency (FF) and Storage-Flow-Frequency (SFF) Relationships

The sole purpose of a *TABLES 5CR1* record is to develop either a FF or SFF relationship for use later by a *5CR2* record.

- A flow-frequency (FF) relationship is between naturalized flow volume over a specified number of months versus exceedance probability developed based on either the log-normal probability distribution or Weibull frequency formula.

- A storage-flow-frequency (SFF) relationship is between the flow ratio $Q_{\%}$ defined by Eq. 7.8 versus exceedance probability developed based on either the log-normal probability distribution or Weibull frequency formula.

The SFF relationship is developed by assigning exceedance probabilities to values of the flow ratio $Q_{\%}$ defined by Eq. 7.8 and either Eqs. 7.9, 7.10, 7.11, or 7.12. Exceedance probabilities are assigned to the naturalized flow sequences as an expression of the relative likelihood of departures of flow volumes from those expected based on relating flow to preceding storage. The basic premise of the SFF option is that naturalized stream flows are correlated to some extent with preceding storage content. Low reservoir storage contents imply dry conditions during preceding months with a high likelihood of continued low naturalized flows. Full reservoirs imply high precipitation during the preceding months with an increased likelihood of continued high flows during subsequent months. Naturalized stream flows are assumed to exhibit some degree of autocorrelation. The likelihood of flows being high during a particular time period is greater if the flows were high in preceding months. Reservoir storage contents are dependent upon flows in preceding months.

The *5CR1* record routines develop either a FF or SFF relationship. Pairs of flow and storage volumes are obtained from the results of a long-term *SIM* simulation. The flow volumes are for naturalized stream flow over a specified number of months at one or more control points. The storage volumes are the storage contents of one or more reservoirs at the beginning of the period over which the naturalized flows occur. Either annual or monthly cycle options may be adopted to define the flow sequences.

Storage limits may be specified on the *5CR1* record such that the only flow sequences considered in developing the SFF or FF array are those with preceding storage falling within the specified range. For example, if lower and upper storage volume limits equal to 25% and 90% of reservoir storage capacity are defined on the *5CR1* record, the set of flow sequences included in the FF and SFF relationship computations include only those flow sequences with preceding storage volume within the range of 25% to 90% of the reservoir capacity.

A flow-frequency (FF) array is based on applying the log-normal probability distribution or Weibull probability formula directly to the naturalized flow volumes. The array assigns exceedance probabilities to flows without considering preceding storage other than through the option that limits the flow sequences included in the computations to a specified storage range.

A storage-flow-frequency (SFF) relationship relates exceedance probability to a flow ratio expressing the deviation of flow volume from that expected based on a given preceding storage volume. The *TABLES 5CR1* record routines perform the following tasks resulting in production of the SFF array.

1. The main *SIM/SIMD* output file with filename extension OUT resulting from a conventional single long-term simulation is read by *TABLES* to obtain the beginning storage and naturalized flow for each simulation sequence.

2. The initial storage at specified control points or for specified reservoirs is summed for each simulation sequence to obtain the total storage amounts used in the analysis. Likewise, naturalized flows during specified months at specified control points are summed to obtain the total flow amounts used in the analysis.

3. Regression analyses are performed to relate flow volume to preceding storage volume in the form of either Eq. 7.9, Eq. 7.10, Eq. 7.11, or Eq. 7.12.

4. The expected value of flow conditioned on storage is computed for each simulation sequence using the regression equation derived from step 3 above. The corresponding values of the flow $Q_{\%}$ in percent are determined with Eq. 7.8.

5. The storage-flow-frequency (SFF) relationship is developed by connecting exceedance frequencies to $Q_{\%}$ using either Eq. 7.19 or Eq. 7.20. The mean and standard deviation of the logarithms of $Q_{\%}$ are computed as the parameters for the log-normal distribution option. Alternatively, an array of $Q_{\%}$ versus exceedance probability is developed using the Weibull formula.

The product of this process activated by a *TABLES 5CR1* record is a SFF relationship connecting exceedance probabilities to values of the flow ratio $Q_{\%}$. The SFF relationship is input to the *TABLES* routine outlined next, which is activated by the *5CR2* record to assign probabilities to each simulation sequence in a conditional reliability modeling application.

<u>*Incremental Probability (IP) Array for the CRM Simulation Sequences*</u>

After the FF or SFF relationship has been established by the *5CR1* record based on the results from a single long-term *SIM/SIMD* simulation, the next task is for the *5CR2* record to develop the IP array by assigning incremental probabilities to each of the multiple simulation sequences of a CRM execution of *SIM/SIMD*. Whereas the *5CR1* record FF and SFF relationships connect the random variable (flow volume or Equation 7.8 flow ratio $Q_{\%}$) to exceedance probabilities, the *5CR2* record computes incremental probabilities for these variables that are assigned to the corresponding hydrologic simulation sequences. The incremental probabilities for all simulation sequences sum to 1.0.

The flow-frequency (FF) option is based on assigning frequencies to naturalized flow sequences without considering reservoir storage contents. With the FF option, *TABLES* assigns probabilities to each of the simulation sequences as follows.

1. The main *SIM/SIMD* output file, with filename extension CRM, resulting from a CRM simulation is read by *TABLES* to obtain the naturalized flow in each month for each simulation sequence.

2. Naturalized flow volumes during specified months at specified control points are summed to obtain the total flow amounts used in the analysis.

3. The naturalized flow volume for each hydrologic sequence is combined with the previously established FF relationship to obtain an exceedance probability for each CRM hydrologic simulation sequence. Linear interpolation is used to obtain exceedance probabilities from either the normal probability table using the FF log-normal probability distribution parameters or the FF Weibull exceedance probability array.

4. The exceedance probabilities are ranked in order and converted to incremental probabilities. The incremental probability for each flow sequence is computed based on the half-way points between exceedance probabilities of the next larger and next smaller flow volumes. The incremental probability is the difference between the two exceedance probabilities.

The storage-flow-frequency (SFF) option considers preceding storage contents in assigning probabilities to the hydrologic simulation sequences. With the SFF option, *TABLES* assigns probabilities to each of the simulation sequences as follows.

1. The main *SIM/SIMD* output file (filename root.CRM) resulting from a CRM run is read by *TABLES* to obtain the naturalized flow in each month for each simulation sequence.

2. The initial storage for each pertinent reservoir or control point is read from either a *5CR2* record or *SIM/SIMD* beginning reservoir storage (filename extension BRS) file.

3. The initial storages at specified reservoirs or control points are summed for each simulation sequence to obtain the total storage amounts used in the analysis. Likewise, naturalized flows during specified months at the specified control points are summed to obtain the total flow amounts used in the analysis.

4. The expected value of flow conditioned on preceding storage is computed for each simulation sequence using either Eq. 7.9, Eq. 7.10, Eq. 7.11, or Eq. 7.12. The corresponding values of the flow ratio $Q_{\%}$ are determined with Eq. 7.8.

5. The value of $Q_{\%}$ for each hydrologic sequence is combined with the previously established SFF relationship using linear interpolation to obtain an exceedance probability for each CRM hydrologic simulation sequence.

6. The exceedance probabilities are ranked in order and converted to incremental probabilities. The incremental probability for each $Q_{\%}$ is computed based on the half-way points between the exceedance probabilities of the next larger $Q_{\%}$ and next smaller $Q_{\%}$. The incremental probability is the difference between the two exceedance probabilities.

The product of this process activated by a *TABLES 5CR2* record is an IP array assigning incremental probabilities to each of the simulation sequences included in the *SIM/SIMD* CRM results. The IP array is used in the reliability and frequency routines activated by *2REL*, *2FRE*, *2FRQ*, and *2RES* records.

Reliability and Frequency Analyses

The probability distribution option is activated by inserting a *5CR2* record in the *TABLES* input file. Without a *5CR2* record, the equal-weight option is adopted by default. The equal-weight option signaled by a *5CRM* record remains in effect until a *5CR2* record is read in the sequence of input records. The incremental probability array created by a *5CR2* record is applied for all subsequent *2REL*, *2FRE*, *2FRQ*, and *2RES* records. The routines activated by these records adopt the last *5CR2* record probability array created during the *TABLES* execution.

With activation of the probability distribution option by a *5CR2* record, all subsequent *2REL*, *2FRE*, *2FRQ*, and *2RES* records incorporate the IP array that assigns incremental probabilities to the CRM simulation sequences. The reliability and frequency analysis computation routines are modified to reflect varying probabilities for the multiple sequences for the probability distribution option. The modifications to the computations are based on counting each simulation sequence multiple times with the count totaling to 1,000,000. The number of times N_S that each simulation sequence is repeated is proportional to incremental probability P_S as follows.

$$N_S = 1{,}000{,}000 \; P_S \tag{7.21}$$

The procedure is illustrated with an example. A water supply diversion CRM reliability table is being constructed for water rights of interest for some selected month of interest, say July, and also for the entire annual simulation period. Frequency tables are being constructed for regulated and unappropriated flows and end-of-month storage contents for a selected month of interest. A 1940-2008 period-of-analysis is divided into 69 annual simulation sequences for the CRM analysis. The *5CR2* record incremental probability array assigns probabilities to each of the 69 simulation sequences as shown in the second column of Table 7.12. The counts from Eq. 7.21 are shown in the last column of the table.

Table 7.12
Example of Applying Probability Array in
Reliability and Frequency Counts

Simulation Sequence	Incremental Probability	N_S Count
1	0.019254	19,254
2	0.025347	25,347
3	0.007469	7,469
4-67	not shown	
68	0.011528	11,528
69	0.017862	17,862
Totals	1.000000	1,000,000

For this example, reliability and frequency analyses for a conventional long-term simulation are based on data from 69 years of simulation results. Likewise, reliability and frequency analyses for a CRM application assuming equally-likely sequences are based on data from 69 simulation sequences. Each sequence is given equal weight and counted one time. However, reliability and frequency analyses for a CRM application using the SFF option is based on data from 69 simulation sequences that are counted as 1,000,000 simulation sequences. The first simulation sequence is counted 19,254 times as shown in the third column of the table above. The second simulation sequence is counted 25,347 times. Thus, the simulation sequences are weighted or counted in proportion to the *5CR2* record probability array.

The reliability and frequency analysis computational routines in *TABLES* count the frequency or number of times that specified magnitudes of specified variables are equaled or exceeded. The algorithms are essentially the same for either a conventional simulation, the CRM equal-weight option, or the CRM probability array option. However, the counts are increased in proportion to incremental probabilities for the CRM probability array option.

Examples 7.2 and 7.3 Based on the Probability Array Approach

The following two examples are probability array versions of the Example 7.1 presented earlier in the chapter which is based on the equal-weight option. The three conditional reliability modeling examples are CRM versions of the conventional long-term simulation example presented in the *Fundamentals Manual*. A schematic of the system of 11 control points and six reservoirs is presented as Figure 1.1 on page 10.

The difference between the preceding example and the following two examples is the method adopted to assign probabilities to each of the hydrologic sequences in the frequency and reliability analysis computations performed within *TABLES*. In the previous example, the 57 sequences are each weighted the same. In the following two examples, probability array computations are adopted to assign varying probabilities to each of 58 hydrologic sequences.

A *CR* record is added to the *SIM* input DAT file to convert to a conditional reliability simulation. The parameters entered on the *CR* record are defined by Table 7.1. The two *CR* records for the three CRM examples are reproduced below.

Example 7.1:	CR	12	4	0	0.10
Examples 7.1 and 7.3:	CR	3	6	0	0.25

Examples 7.2 and 7.3 are based on the same *SIM* simulation. For Examples 7.2 and 7.3, the *CR* record divides the 1940-1997 period-of-analysis into 58 three-month hydrologic sequences covering June (month 6) through August (month 8). The reservoirs all have beginning-of-month storage contents at the beginning of each June of 25 percent of their storage capacities.

Examples 7.2 and 7.3 differ from each other as follows.

1. Development of the probability array in Example 7.2 focuses on Granger Reservoir. Although the entire basin is simulated in all cases, the probability array is designed to maximize the accuracy of the probability estimates at Granger Reservoir. Thus, the probability array for Example 7.2 is developed based on storage in Granger Reservoir and naturalized flow at control point Grang.

2. Example 7.3 is concerned with the accuracy of the probability estimates in general for the entire river basin system. The probability array is developed based on storage in all six reservoirs and naturalized flow at control point Hemp.

Input and Output Files for CRM Examples 7.2 and 7.3

The example in the *Fundamentals Manual* has a *SIM* input dataset consisting of DAT, FLO, and EVA files with the following filenames. *WRAP-SIM* stores the simulation results in an output file with the filename extension OUT.

FundExam.DAT
FundExam.FLO
FundExam.EVA
FundExam.OUT

Examples 7.2 and 7.3 include the following input and output files.

CrmExam.DAT	− FundExam.DAT with *CR* record added
CrmExam.FLO	− FundExam.FLO (no change) containing naturalized flows
CrmExam.EVA	− FundExam.EVA (no change) with net evaporation rates
CrmExam.OUT	− FundExam.OUT (no change) for long-term *SIM* simulation
CrmExam.CRM	− *SIM* output file with CRM simulation results
CrmExam.BRS	− *SIM* beginning reservoir storage file used by 5CRM2 record
CrmExam.TMS	− *TABLES* message file
CrmExam.SFF	− *TABLES* output file with probability arrays
CrmExam.TOU	− *TABLES* main output file

The FLO and EVA files from the *Fundamentals Manual* example are adopted without modification for the CRM examples. The conditional reliability modeling DAT file is created by adding a *CR* record to the *Fundamentals Manual* DAT file. The *SIM* output OUT file for the conventional long-term simulation is required by the *5CR1* record. The *5CR2* record operations in *TABLES* include reading the CRM and BRS files created by *SIM*.

The flow ratio (percentage) versus exceedance probability table created by the *5CR1* record is written in a storage-flow-frequency (SFF) file. The flow ratio (percentage) versus incremental probability table created by the *5CR2* record is also recorded in the SFF file. *TABLES* also creates its normal TMS and TOU output files.

<u>Example 7.2 with Probability Array Based on Storage and Flows at Lake Granger</u>

The *TABLES* input TIN file for Example 7.2 is reproduced as Table 7.13. The BRS file shown as Table 7.15 was created by *SIM* and read by *TABLES* for both Examples 2 and 3. The TMS, SFF, and TOU output files created by *TABLES* are shown as Tables 7.14 and 7.16−7.19.

The 5CR1 record in the TIN file of Table 7.13 controls the development of a two-dimensional array (table) of exceedance probability versus naturalized stream flow volume expressed as a percentage of the flow volume predicted with a regression equation. The resulting array is tabulated in the SFF file reproduced as Table 7.16.

5CR1 record computations use storage and flow data obtained by reading the OUT file for a conventional long-term *SIM* simulation. Beginning-of-June storage volumes in Lake Granger are related to 3-month (June−August) volumes of naturalized flows at control point Grang. FILE2 option 4 activated in 5CR1 column 76 results in creation of a listing in the TMS file of Table 7.14 with the following information for each of the 58 hydrologic sequences.

- beginning-of-June storage contents of Lake Granger
- 3-month total of June-August naturalized flow volume
- rank index for storage volumes with the smallest volume having a rank of 1
- rank index for flow volumes with the smallest volume having a rank of 1

Statistics for these data are presented in Table 7.17. The linear correlation coefficient for storage versus flow volume is 0.2456. The Pearson correlation coefficient of 0.5639 is the linear correlation coefficient for the flow rank versus storage rank.

Table 7.13

TABLES Input TIN File for CRM Example 7.2

```
**   TABLES Input File CrmExam2.TIN
**   CRM Example 2
**       1         2         3         4         5         6         7
**  567890123456789012345678901234567890123456789012345678901234567890123456
****---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!
5CR1   1   1   6   3   0   1                                               4
5CR1FLOW   Grang
5CR1STRE   Grang
5CR2   1   1   1   3   1   1   1
5CR2FLOW   Grang
5CR2STRE   Grang
**    Diversion Reliability Tables
2REL   0
**    Reservoir Storage Frequency Tables
2FRE   6   6
2FRE   6   7
2FRE   6   8
ENDF
```

Table 7.14

TABLES Message TMS File for CRM Example 7.2

```
  TABLES MESSAGE FILE

*** File was opened: CrmExam.TIN
*** File was opened: CrmExam.TOU
*** Identifiers for the 18 records in the TIN file were checked.
*** File was opened: CrmExam.CRM
*** File was opened: CrmExam.OUT
*** Tables are being developed as specified by a 5CR1 record.

 FILE2 option 4 results in the following tabulation
 of arrays developed by 5CR1 or 5COR records.

Sequence   Storage        Flow   Storage Rank Flow Rank
    1      36617.6     126132.0       19.       56.
    2      65500.0      79073.0       27.       52.
    3      65500.0      46599.0       27.       44.
    4      65500.0       3408.0       27.       10.
    5      65500.0      56998.0       27.       47.
    6      65500.0      51811.0       27.       46.
    7      65500.0      15442.0       27.       26.
    8      65500.0       9399.0       27.       19.
    9      59204.6       6403.0       24.       15.
   10      17385.5      11983.0       10.       22.
   11       4151.0       7214.0        6.       16.
   12          0.0       1045.0        1.        3.
   13      24440.3       5837.0       15.       13.
   14      22364.2       5274.0       12.       12.
   15       1514.2        162.0        4.        1.
   16       9222.9      19658.0        7.       30.
   17       1140.3        240.0        3.        2.
   18      65500.0      92636.0       27.       54.
   19      65500.0      17802.0       27.       28.
   20      49122.0      19528.0       23.       29.
   21      65500.0       8307.0       27.       18.
   22      63029.6      33799.0       26.       38.
   23      65500.0      15992.0       27.       27.
   24      38911.7       1483.0       20.        4.
```

Table 7.14 Continued
TABLES Message TMS File for CRM Example 7.2

25	11051.4	4219.0	8.	11.
26	65500.0	39852.0	27.	42.
27	65500.0	25890.0	27.	35.
28	27078.6	2728.0	16.	9.
29	65500.0	58392.0	27.	48.
30	65500.0	29644.0	27.	36.
31	65500.0	33263.0	27.	37.
32	14599.8	10307.0	9.	20.
33	23007.0	20920.0	14.	31.
34	65500.0	34019.0	27.	40.
35	65500.0	42312.0	27.	43.
36	65500.0	76631.0	27.	51.
37	65500.0	50211.0	27.	45.
38	65500.0	15171.0	27.	25.
39	1603.5	1515.0	5.	5.
40	65500.0	74563.0	27.	49.
41	65500.0	5850.0	27.	14.
42	19834.7	248018.0	11.	58.
43	65500.0	21131.0	27.	32.
44	62432.9	33975.0	25.	39.
45	0.0	7399.0	1.	17.
46	65500.0	12521.0	27.	23.
47	65500.0	35862.0	27.	41.
48	65500.0	173387.0	27.	57.
49	22933.5	14540.0	13.	24.
50	33288.2	10471.0	18.	21.
51	43061.9	1660.0	22.	6.
52	65500.0	24598.0	27.	34.
53	65500.0	90031.0	27.	53.
54	65500.0	76625.0	27.	50.
55	42220.6	2513.0	21.	8.
56	65500.0	24002.0	27.	33.
57	31792.1	2370.0	17.	7.
58	65500.0	114774.0	27.	55.

```
*** Tables are being developed as specified by a 5CR2 record.
*** Tables are being developed as specified by a 2REL record.
*** Tables are being developed as specified by a 2FRE record.
*** Tables are being developed as specified by a 2FRE record.
*** Tables are being developed as specified by a 2FRE record.

    Program TABLES output is in file CrmExam.TOU
    Date:  20-MAR-10
    Time:  09:01:41

  ***** Normal Completion of Program TABLES
```

June-August naturalized flow volume (Q) at control point Grang is related to beginning-of-June storage contents (S) of Lake Granger in the 5CR1 record operations with the exponential regression equation. For the exponential model of Equation 7.9, the natural logarithm of the flow volume Q is regressed with the storage volume S using standard least squares linear regression (Eqs. 7.13, 7.14, 7.15). The resulting coefficients shown in Table 7.17 are as follows.

$$Q = 2{,}505.64\ e^{(S\ /\ 26{,}059)}$$

Application of linear correlation (Eq. 7.17) to S versus the natural logarithm of Q results in the correlation coefficient (r) of 0.6008 shown in Table 7.17. Correlation coefficients for the four regression options selected by FIT in 5CR1 record field 7 are compared as follows. Thus, option 1 results in the best (closest to 1.00) value for the correlation coefficient.

FIT Option	Equation	Correlation Coefficient (r)
1 exponential	7.9	0.6008
2 combined	7.10	0.2592
3 linear	7.11	0.2456
4 power	7.12	0.4705

The variable $Q_{\%}$ is defined as the June-August flow volume at control point Grang expressed as a percentage of the flow volume computed by the regression equation as a function of beginning-of-June storage contents of Lake Granger. The random variable $Q_{\%}$ is modeled with the log-normal probability distribution as specified by the *5CR1* record. The resulting table of $Q_{\%}$ versus exceedance probability is tabulated in the SFF file reproduced as Table 7.16.

The *5CR2* record uses the $Q_{\%}$ versus exceedance probability array to develop the $Q_{\%}$ versus incremental probability array which is also recorded in Table 7.16. The *5CR2* record routine reads the beginning-of-June storage volumes and June-August flow volumes from the *SIM* simulation results CRM file. Since end-of-month storage volumes are recorded in the CRM file, *TABLES* reads the BRS file created by *SIM* to obtain the beginning-of-month storage contents for the first month of the *SIM* simulation. The BRS file is reproduced as Table 7.15. The regression equation and coefficients developed with the *5CR1* record are applied to develop a $Q_{\%}$ for each of the 58 flow sequences. Incremental probabilities are assigned to each sequence based on interpolation of the $Q_{\%}$ versus exceedance probability array.

Table 7.15
Beginning Reservoir Storage (BRS) File for Examples 7.2 and 7.3

```
Beginning Reservoir Storage (BRS) File

                Control   Storage  Beginning
Reservoir        Point   Capacity   Storage

1     PK    1     PK  570240.0  142560.0
2   Whit    2   Whit  627100.0  156775.0
3  WacoL    3  WacoL  192100.0   48025.0
4 Belton    6 Belton  457600.0  114400.0
5 George    7 George   37100.0    9275.0
6  Grang    8  Grang   65500.0   16375.0
```

The incremental probability array tabulated in the second half of Table 7.16 assigns a probability to each of the 58 hydrologic sequences. For example, the first two sequences (June-August 1940 and June-August 1941) have probabilities of 0.0014460 and 0.0016638. With the alternative equal-weight option, each sequence would have a probability of 1/58 = 0.0172414.

The only purpose of the *5CR1* record is to develop a $Q_{\%}$ versus exceedance probability array to be used in the *5CR2* record computations. The sole purpose of the *5CR2* record is to develop a $Q_{\%}$ versus incremental probability array. The incremental probability array is used in *2FRE*, *2FRQ*, *2REL*, and *2RES* record operations to assign probabilities to each of the hydrologic sequences in the frequency and reliability analyses.

Table 7.16
TABLES SFF File for CRM Example 7.2

```
SFF Array for CR1 of  3 months and CR2 of month 6
   Flow Percent  Frequency
      20760.426   0.000010
       9494.746   0.000100
       4623.854   0.000863
       1234.938   0.020008
        560.387   0.079562
        550.698   0.081691
        370.950   0.142090
        345.313   0.155659
        299.400   0.185151
        295.283   0.188188
        290.980   0.191440
        255.564   0.221669
        247.672   0.229363
        247.652   0.229382
        245.515   0.231539
        245.417   0.231639
        240.988   0.236193
        240.680   0.236515
        234.907   0.242676
        188.723   0.301923
        184.218   0.308845
        167.453   0.336809
        162.282   0.346220
        150.608   0.368979
        136.752   0.399083
        128.802   0.418088
        123.523   0.431491
        120.101   0.440521
        118.326   0.445326
        116.492   0.450373
        115.906   0.452004
        110.182   0.468432
        109.949   0.469118
        107.506   0.476426
         95.809   0.513950
         91.192   0.530023
         89.229   0.537094
         83.677   0.557881
         79.501   0.574336
         77.574   0.582176
         68.295   0.622305
         57.536   0.674214
         56.855   0.677712
         51.686   0.705121
         49.909   0.714907
         49.033   0.719796
         41.704   0.762543
         40.468   0.770074
         38.516   0.782148
         30.378   0.834826
         27.925   0.851336
         26.848   0.858656
         26.350   0.862058
         19.844   0.906792
         18.907   0.913205
         13.296   0.950368
         12.692   0.954143
         11.015   0.964243
          9.168   0.974535
          6.100   0.988844
          0.000   1.000000
          0.000   0.000000
          0.000   0.000000
          0.000   0.000000
*************************
```

Table 7.16 Continued

TABLES SFF File for CRM Example 7.2

```
Probability Array for CR1 of  3 months and CR2 of month 6
   Flow Percent   Frequency
       2685.371   0.0014582
       1683.477   0.0016745
        992.101   0.0049044
         72.557   0.0682523
       1213.497   0.0025880
       1103.065   0.0028682
        328.763   0.0053161
        200.106   0.0301275
        136.321   0.0329407
        255.120   0.0223459
        153.587   0.0224281
         22.248   0.0827892
        124.271   0.0167258
        112.284   0.0526927
          3.449   0.0052638
        418.522   0.0055139
          5.110   0.0533907
       1972.236   0.0017021
        379.008   0.0181250
        415.754   0.0085472
        176.857   0.0348849
        719.586   0.0009458
        340.472   0.0136275
         31.573   0.0339428
         89.823   0.0705419
        848.456   0.0060627
        551.202   0.0109670
         58.080   0.0459698
       1243.175   0.0043836
        631.126   0.0133485
        708.175   0.0063477
        219.438   0.0146010
        445.390   0.0057371
        724.270   0.0023018
        900.830   0.0049562
       1631.487   0.0003692
       1069.001   0.0027461
        322.993   0.0062633
         32.255   0.0122977
       1587.459   0.0042385
        124.547   0.0147367
       5280.345   0.0010989
        449.883   0.0099172
        723.333   0.0002862
        157.526   0.0211411
        266.574   0.0220642
        763.508   0.0062741
       3691.438   0.0014955
        309.559   0.0212470
        222.929   0.0191638
         35.342   0.0552477
        523.696   0.0048709
       1916.775   0.0015545
       1631.359   0.0003403
         53.502   0.0202113
        511.007   0.0107679
         50.458   0.0534786
       2443.558   0.0019166
                ------------
          Sum =   1.0000000
```

The *TABLES* input TIN file of Table 7.13 creates the *TABLES* output TOU file shown as Tables 7.17, 7.18, and 7.19. The *2REL* water supply diversion reliability indices and *2FRE* storage frequency statistics are presented in Tables 7.18 and 7.19. Reliability and frequency tables have the same format and interpretation with either of the alternative equal-weight or probability array methods for estimating probabilities.

Table 7.17
5CR1 Record Statistics from TOU File for CRM Example 7.2

```
5CR1 RECORD STATISTICS FOR SFF RELATIONSHIP

Beginning-of-month storage contents in month  6
Naturalized flows for  3 months beginning in month 6

Storage in reservoir(s):      Grang
Flows at control point(s):    Grang

Storage and Flow Statistics:
                 Storage     Flow(Q)  (Q/Qp)100%
    Mean         47517.4     35441.2   236.975
    Std Dev      23971.7     45483.5   615.937
    Minimum          0.0       162.0     6.100
    Maximum      65500.0    248018.0  4623.854

Linear correlation coefficient for storage versus flow volume   =  0.2456
Spearman correlation coefficient for storage versus flow volume =  0.5639

Regression and correlation coefficients for FIT = 1
Exponential Regression,  Q = a*exp^(S/b),   a = 2505.638   b = 26059.021   R = 0.6008
```

Table 7.18
Reliability Table from TOU File for CRM Example 7.2

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

```
CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 6
Length of simulation period (CR1) is  3 months.
Initial storage multiplier (CR4) =  0.250
```

NAME	TARGET DIVERSION (AC-FT/SQ)	MEAN SHORTAGE (AC-FT/SQ)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF SEQUENCES PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
PK	82724.1	3794.55	89.06	95.41	89.1	89.1	92.0	94.4	96.3	96.5	98.2	72.5	72.5	81.5	88.5	89.5	100.0	100.0
Whit	5850.0	5585.24	4.44	4.53	4.4	4.4	4.4	4.5	4.5	4.5	4.5	3.7	3.7	3.7	3.9	3.9	4.3	5.3
WacoL	26260.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
WacoG	24095.8	5839.44	66.52	75.77	66.5	68.6	69.8	73.7	79.7	81.9	83.0	27.5	33.3	36.8	41.7	62.8	81.1	100.0
High	33420.8	11796.35	58.24	64.70	58.2	58.9	59.1	62.1	67.9	75.4	81.5	21.5	23.5	24.1	27.7	32.7	72.2	100.0
Belton	58550.3	3943.19	91.82	93.27	91.8	91.8	91.8	92.0	94.5	94.5	94.5	82.8	82.8	83.5	83.5	83.5	94.7	100.0
George	8254.7	607.60	91.04	92.64	91.0	91.0	91.0	91.3	92.5	93.0	95.0	75.9	75.9	75.9	77.4	79.0	100.0	100.0
Grang	13537.5	1519.14	85.06	88.78	85.1	85.1	85.1	85.4	87.9	91.8	95.0	59.6	59.6	60.6	60.7	75.8	97.3	100.0
Camer	112344.0	48901.12	22.59	56.47	22.6	22.8	25.0	31.1	51.7	93.8	100.0	1.6	1.6	2.1	2.2	20.6	63.1	100.0
Bryan	48588.0	8661.57	41.96	82.17	42.0	42.0	48.9	73.2	98.0	98.2	100.0	13.3	13.3	26.5	36.1	62.8	100.0	100.0
Hemp	418614.2	82711.78	30.23	80.24	30.2	33.9	40.3	75.4	87.2	94.5	100.0	5.1	5.4	16.1	34.1	70.5	94.7	100.0
Total	832239.4	173359.97		79.17														

Table 7.19
Reservoir Storage Frequency Statistics from TOU File for CRM Example 7.2

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 6

CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 6
Length of simulation period (CR1) is 3 months.
Initial storage multiplier (CR4) = 0.250

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
RESERVOIR	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	165512.	7624954.	21287.	21287.	21287.	21287.	23198.	125606.	146365.	149355.	155691.	166681.	328403.	570240.
Whit	206670.	6069357.	152326.	152326.	152413.	152413.	153859.	155567.	176777.	180926.	189592.	222475.	281493.	586512.
WacoL	62404.	2113276.	38455.	38455.	38455.	38455.	39245.	42414.	44581.	50953.	62057.	76840.	99720.	192100.
Belton	109338.	3726378.	9440.	9440.	9440.	9440.	67555.	85322.	101146.	104376.	111138.	123378.	156934.	336795.
George	7897.	290394.	907.	1574.	1574.	6351.	6351.	6474.	6666.	6823.	7203.	8114.	9673.	37100.
Grang	14105.	644452.	0.	0.	0.	0.	5182.	12597.	12857.	13304.	13602.	15981.	22794.	65500.
Total	565926.	17084276.	318660.	318660.	318660.	318660.	323864.	431469.	489618.	520187.	536219.	634578.	894034.	1477631.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 7

CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 6
Length of simulation period (CR1) is 3 months.
Initial storage multiplier (CR4) = 0.250

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
RESERVOIR	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	113347.	9197430.	0.	0.	0.	0.	0.	5109.	30737.	66740.	131683.	208616.	253476.	570240.
Whit	207892.	6102984.	147699.	147699.	149192.	149192.	149730.	151778.	174213.	178595.	194217.	245140.	277924.	627100.
WacoL	56544.	2469274.	27223.	27223.	27223.	27223.	27866.	33205.	42738.	52034.	54094.	68716.	92962.	192100.
Belton	73944.	4540028.	0.	0.	0.	0.	0.	36842.	67701.	75288.	80318.	94759.	160074.	371750.
George	4458.	376937.	0.	0.	0.	0.	0.	1985.	3578.	3630.	4328.	5498.	7738.	37100.
Grang	6713.	705341.	0.	0.	0.	0.	0.	0.	1179.	6196.	9057.	9933.	13673.	65500.
Total	462898.	19766198.	177058.	177058.	177058.	177058.	184983.	288973.	348109.	408827.	454774.	546867.	750748.	1689081.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 8

CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 6
Length of simulation period (CR1) is 3 months.
Initial storage multiplier (CR4) = 0.250

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
RESERVOIR	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	74469.	8573134.	0.	0.	0.	0.	0.	0.	0.	4572.	47976.	140432.	235205.	570240.
Whit	211212.	6315440.	141311.	141311.	143440.	143440.	146436.	151187.	169643.	189564.	202388.	239412.	283116.	627100.
WacoL	50016.	2751718.	16432.	16432.	16432.	16432.	19494.	22247.	35064.	42181.	44533.	57264.	81045.	192100.
Belton	40303.	4652922.	0.	0.	0.	0.	0.	0.	0.	0.	43323.	61694.	150639.	365556.
George	1701.	283047.	0.	0.	0.	0.	0.	0.	0.	0.	996.	2717.	4449.	35201.
Grang	3317.	540002.	0.	0.	0.	0.	0.	0.	0.	0.	18.	6077.	9951.	59912.
Total	381019.	19633990.	158998.	158998.	159871.	159871.	170194.	222237.	252561.	293054.	336908.	463134.	638401.	1807583.

Example 7.3 with Probability Array Based on Storage
in Six Reservoirs and Flows at Control Point Hemp

The same *SIM* input dataset and resulting *SIM* output OUT, CRM, and BRS files are used in both Examples 7.2 and 7.3. The *TABLES* input TIN, message TMS, and output TOU files for Example 3 are reproduced as Tables 7.20−7.24. The *5CR1* and *5CR2* records in Table 7.20 relate the annual June through August volumes of naturalized flows at control point Hemp to the total storage volume in the six reservoirs at the beginning of June. Flow volume is related to preceding storage using exponential regression (Eq. 7.9). The random variable $Q_{\%}$ is modeled with the log-normal distribution. Regression and correlation statistics are shown in Table 7.22.

The 58 three-month June-August naturalized flow volumes (acre-feet) at control point Hemp and the corresponding total beginning-of-June storage contents (acre-feet) of the six reservoirs are tabulated in the TMS file of Table 7.21. The following coefficients from Table 7.22 provide an index of the correlation between these 3-month flow volumes in acre-feet at control point Hemp and preceding storage contents of the six reservoirs.

linear correlation coefficient (r) = 0.3649
Spearman rank correlation coefficient (r_r) = 0.3646

The linear correlation coefficient (r in Eq. 7.17) of 0.6008 for storage S versus the natural logarithm of flow Q is included in Table 7.22. Alternative executions of *TABLES* provide the following comparison of correlation coefficients for the four regression options. Option 1 results in the best (closest to 1.00) value for the correlation coefficient.

FIT Option	Equation	Correlation Coefficient (r)
1 exponential	7.9	0.4283
2 combined	7.10	0.3060
3 linear	7.11	0.3649
4 power	7.12	0.3860

The reliability and frequency tables presented as Tables 7.23 and 7.24 can be compared with the corresponding Example 7.2 Tables 7.18 and 7.19. All of the 11 control points are included in the water supply reliability tables, and all six reservoirs are included in the storage frequency tables for both examples. However, development of the storage-flow-frequency (SFF) relationship upon which the reliability and frequency estimates are based differ between the two examples. The SFF relationship in Example 7.2 is designed for maximum accuracy in estimating reliabilities and frequencies associated with Granger Reservoir. The SFF relationship in Example 3 is designed for more general applicability in estimating reliabilities and frequencies associated with all of the reservoirs and control points throughout the river basin.

A variety of *5CR1* and *5CR2* options can be combined in various ways to develop storage-flow-frequency (SFF) relationships. A variety of stream flow locations and time periods may also be considered. Frequency and reliability estimates may vary significantly with different computational methods and choices of locations and time periods. The alternative CRM options are compared in the last section of this chapter.

Table 7.20
Tables Input TIN File for CRM Example 7.3

```
**   TABLES Input File CrmExam3.TIN
**   CRM Example 3
**       1         2         3         4         5         6         7
**  5678901234567890123456789012345678901234567890123456789012345678901234567890123456
****---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!---!
5CR1   1   6   6   3   0   1                                                  4
5CR1FLOW    Hemp
5CR1STRE      PK    Whit   WacoL  Belton  George   Grang
5CR2   1   6   1   3   1   1   1
5CR2FLOW    Hemp
5CR2STRE      PK    Whit   WacoL  Belton  George   Grang
**    Diversion Reliability Table
2REL
**    Reservoir Storage Frequency Tables
2FRE   6   6
2FRE   6   7
2FRE   6   8
ENDF
```

Table 7.21
TABLES Message TMS File for CRM Example 7.3

```
   TABLES MESSAGE FILE

*** File was opened: CrmExam.TIN
*** File was opened: CrmExam.TOU
*** Identifiers for the 18 records in the TIN file were checked.
*** File was opened: CrmExam.CRM
*** File was opened: CrmExam.OUT
*** Tables are being developed as specified by a 5CR1 record.

 FILE2 option 4 results in the following tabulation
 of arrays developed by 5CR1 or 5COR records.

Sequence   Storage        Flow   Storage Rank Flow Rank
    1    1786722.9    2105832.0       35.       52.
    2    1949640.0    3354824.0       44.       58.
    3    1949640.0    1534722.0       44.       42.
    4    1937234.9     366753.0       43.       11.
    5    1696583.0    1235206.0       30.       38.
    6    1872378.4    1366911.0       37.       40.
    7    1887587.5    1025551.0       38.       35.
    8    1949640.0     714433.0       44.       25.
    9    1426957.0     499547.0       23.       20.
   10    1340205.8     734207.0       18.       30.
   11    1311259.5    1004171.0       16.       33.
   12     846242.9     440247.0        5.       16.
   13     714586.8     232878.0        2.        4.
   14     842761.9     486615.0        4.       18.
   15     968142.4     210812.0        9.        3.
   16     903522.9     586610.0        7.       23.
   17    1102410.9      62778.0       11.        1.
   18    1949640.0    2094484.0       44.       51.
   19    1949640.0     719618.0       44.       27.
   20    1383528.8     878081.0       20.       31.
   21    1894691.8     726137.0       41.       28.
   22    1903885.4    1959494.0       42.       50.
```

Table 7.21 Continued

TABLES Message TMS File for CRM Example 7.3

23	1696456.4	963200.0	29.	32.
24	1809956.4	306284.0	36.	7.
25	886881.4	295306.0	6.	6.
26	1770958.2	1019416.0	34.	34.
27	1949640.0	625667.0	44.	24.
28	1480875.4	489223.0	25.	19.
29	1949640.0	2597231.0	44.	56.
30	1949640.0	460837.0	44.	17.
31	1949640.0	413444.0	44.	14.
32	975132.0	733955.0	10.	29.
33	1419267.2	353481.0	21.	10.
34	1609136.4	1698325.0	27.	46.
35	1377057.6	346328.0	19.	9.
36	1949640.0	1607507.0	44.	44.
37	1659243.6	1429990.0	28.	41.
38	1949640.0	428587.0	44.	15.
39	836991.2	716067.0	3.	26.
40	1457111.0	2535006.0	24.	55.
41	1422062.0	247005.0	22.	5.
42	946616.9	2516210.0	8.	54.
43	1705593.9	1574298.0	32.	43.
44	1207547.6	542116.0	13.	22.
45	513079.4	141687.0	1.	2.
46	1523818.2	402506.0	26.	13.
47	1317929.1	1707045.0	17.	47.
48	1949640.0	3078269.0	44.	57.
49	1306192.2	390152.0	15.	12.
50	1177829.1	1733968.0	12.	48.
51	1890101.9	1047569.0	40.	36.
52	1698082.2	1137060.0	31.	37.
53	1949640.0	2495621.0	44.	53.
54	1949640.0	1286302.0	44.	39.
55	1889598.9	522987.0	39.	21.
56	1734136.8	1697035.0	33.	45.
57	1241971.8	327177.0	14.	8.
58	1949640.0	1742622.0	44.	49.

```
*** Tables are being developed as specified by a 5CR2 record.
*** Tables are being developed as specified by a 2REL record.
*** Tables are being developed as specified by a 2FRE record.
*** Tables are being developed as specified by a 2FRE record.
*** Tables are being developed as specified by a 2FRE record.

    Program TABLES output is in file CrmExam.TOU
    Date:  20-MAR-10
    Time:  09:16:10

  ***** Normal Completion of Program TABLES *****
```

Table 7.22
5CR1 Record Statistics from TOU File for CRM Example 7.3

```
5CR1 RECORD STATISTICS FOR SFF RELATIONSHIP

Beginning-of-month storage contents in month  6
Naturalized flows for  3 months beginning in month 6

Storage in reservoir(s):      PK      Whit    WacoL   Belton  George  Grang
Flows at control point(s):    Hemp

Storage and Flow Statistics:
                 Storage     Flow(Q)  (Q/Qp)100%
    Mean       1545119.5    1068093.0   128.549
    Std Dev     410420.9     799973.6    97.777
    Minimum     513079.4      62778.0    12.363
    Maximum    1949640.0    3354824.0   578.456

Linear correlation coefficient for storage versus flow volume   =  0.3984
Spearman correlation coefficient for storage versus flow volume =  0.4405

Regression and correlation coefficients for FIT = 1
Exponential Regression,  Q = a*exp^(S/b),
                             a = 169896.027   b = 1006900.596   R = 0.4856
```

Table 7.23
Water Supply Diversion Reliability Table from TOU File for CRM Example 2.3

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 6
Length of simulation period (CR1) is 3 months.
Initial storage multiplier (CR4) = 0.250

NAME	TARGET DIVERSION (AC-FT/SQ)	MEAN SHORTAGE (AC-FT/SQ)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF SEQUENCES PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	1%
PK	82724.1	11177.06	77.53	86.49	77.5	77.5	79.1	81.1	85.1	88.9	96.6	42.8	42.8	47.6	53.4	66.7	100.0	100.0
Whit	5850.0	5821.10	0.48	0.49	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.5	0.6
WacoL	26260.0	0.00	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
WacoG	24095.8	8784.51	56.38	63.54	56.4	58.2	58.9	60.1	69.7	72.2	75.8	17.0	22.3	22.5	23.5	36.9	60.9	100.0
High	33420.8	15378.08	43.95	53.99	44.0	44.6	45.1	52.0	59.3	66.5	70.4	8.8	10.3	11.7	12.0	20.8	54.2	100.0
Belton	58550.3	10518.42	77.68	82.04	77.7	77.7	77.7	78.2	84.2	84.2	84.2	51.1	51.1	52.5	52.5	52.5	98.8	100.0
George	8254.7	1583.79	74.79	80.81	74.8	74.8	74.8	75.3	83.0	84.7	86.3	42.6	42.6	42.6	49.0	54.2	100.0	100.0
Grang	13537.5	3471.58	70.03	74.36	70.0	70.0	70.0	70.7	71.6	77.0	86.3	32.5	32.5	32.6	34.5	43.6	81.8	100.0
Camer	112344.0	60664.57	16.80	46.00	16.8	16.9	18.7	21.6	36.2	78.6	100.0	1.0	1.0	1.1	1.1	11.0	40.1	100.0
Bryan	48588.0	11827.54	24.20	75.66	24.2	24.2	26.8	66.8	96.1	96.6	100.0	4.3	4.3	9.6	16.7	46.3	100.0	100.0
Hemp	418614.3	133270.84	20.11	68.16	20.1	21.6	32.2	59.8	75.0	83.1	100.0	3.3	3.8	7.1	19.8	35.0	89.8	100.0
Total	832239.4	262497.50		68.46														

Table 7.24
Reservoir Storage Frequency Statistics from TOU File for CRM Example 7.3

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 6

```
CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 6
Length of simulation period (CR1) is  3 months.
Initial storage multiplier (CR4) =  0.250
```

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
RESERVOIR	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	123997.	6588770.	21287.	21287.	21287.	21287.	21287.	50021.	113428.	113428.	134112.	155026.	216525.	570240.
Whit	176543.	2444394.	152326.	152326.	152326.	152413.	153859.	155567.	155946.	168425.	177109.	186966.	213259.	586512.
WacoL	54637.	1409539.	38455.	38455.	39245.	39342.	40323.	43724.	43724.	44917.	50953.	57662.	86057.	192100.
Belton	87229.	3234948.	9440.	9440.	15420.	15420.	15420.	68121.	84325.	85322.	101146.	107271.	136766.	336795.
George	6693.	291777.	907.	907.	1574.	1574.	1574.	6338.	6351.	6454.	6666.	8114.	9373.	37100.
Grang	11536.	687077.	0.	0.	0.	0.	0.	0.	12407.	12515.	12857.	15315.	20376.	65500.
Total	460635.	11341433.	318660.	318660.	318660.	318660.	318660.	330092.	397379.	419596.	488517.	526831.	660119.	1477631.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 7

```
CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 6
Length of simulation period (CR1) is  3 months.
Initial storage multiplier (CR4) =  0.250
```

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
RESERVOIR	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	49817.	7051632.	0.	0.	0.	0.	0.	0.	0.	5109.	19421.	56538.	180532.	570240.
Whit	175456.	2930692.	147699.	147699.	147699.	149192.	149192.	151030.	151030.	162975.	176182.	180028.	221783.	627100.
WacoL	45945.	1664431.	27223.	27223.	27866.	27866.	27866.	33205.	34292.	39002.	43475.	52034.	83032.	192100.
Belton	38132.	3788872.	0.	0.	0.	0.	0.	0.	0.	0.	43811.	75288.	101629.	371750.
George	2513.	323701.	0.	0.	0.	0.	0.	0.	0.	0.	1985.	4328.	6846.	37100.
Grang	3292.	549849.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3688.	10975.	65500.
Total	315153.	13970360.	177058.	177058.	177058.	177058.	177058.	185323.	228051.	228926.	288973.	357762.	531376.	1689081.

STORAGE-FREQUENCY FOR SPECIFIED RESERVOIRS FOR MONTH 8

```
CONDITIONAL RELIABILITY MODELING: Probability Array Option
Annual cycles starting in month 6
Length of simulation period (CR1) is  3 months.
Initial storage multiplier (CR4) =  0.250
```

		STANDARD	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
RESERVOIR	MEAN	DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
PK	25455.	5345912.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	66922.	570240.
Whit	176140.	3359070.	141311.	141311.	141311.	143440.	143440.	147350.	148933.	157848.	172639.	189564.	231335.	627100.
WacoL	37865.	1741294.	16432.	16432.	16432.	16432.	16432.	22247.	27828.	29908.	35785.	43281.	74878.	192100.
Belton	16597.	3040752.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	70899.	365556.
George	788.	193042.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3321.	35201.
Grang	1337.	327948.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	5353.	59912.
Total	258183.	12092673.	158998.	158998.	158998.	159871.	159871.	175178.	180095.	208423.	222237.	269188.	378249.	1807583.

Summary Comparison of CRM Options

Water supply, hydroelectric power, and environmental instream flow reliabilities and reservoir storage levels over the next several months depend on both the:

1. amount of water currently available in reservoir storage
2. hydrology that occurs over the future several-month period of interest as represented by naturalized flows and net reservoir evaporation rates

Beginning reservoir storage and naturalized stream flow represent the two sources of available water. The relative importance of these two sources in determining supply reliabilities and end-of-period storage frequencies depends upon their relative magnitude. Beginning reservoir storage is specified by the model-user the same with either the equal-weight or probability array options. The probability array option methodology deals with the hydrology, focusing on improving probability estimates assigned to each of the individual hydrologic sequences.

The final results of CRM analyses are organized in the format of reliability and frequency tables created by *2REL*, *2FRE*, *2FRQ*, and *2RES* records. Other auxiliary tables may be created as well. The format and content of these tables displaying CRM results are the same regardless of the options adopted to perform the computations. Of course, the numerical values of the reliability and frequency estimates will vary depending on the computational techniques chosen. The choices of computational options are outlined in Table 7.25.

Table 7.25
Outline of CRM Computational Options

1. Equal-Weight Option
   - ∗ choice of annual or monthly cycle options (*CR* record)
2. Probability Array Option (*CR* record, *5CR1* and *5CR2* records)
   - Flow-Frequency (FF) Relationship Option
     - ∗ choice of annual or monthly cycle options
     - ∗ selection of control points for naturalized flows
     - ∗ upper and lower limits defining reservoir storage range
     - ∗ choice of log-normal or Weibull (Eq. 7.19 or Eq. 7.20)
   - Storage-Flow-Frequency (SFF) Relationship Option (Eq. 7.8)
     - ∗ choice of annual or monthly cycle options
     - ∗ selection of control points for storages and flows
     - ∗ upper and lower limits defining reservoir storage range
     - ∗ choice of regression equation (Eq. 7.9, 7.10, 7.11, or 7.12)
     - ∗ choice of log-normal or Weibull (Eq. 7.19 or Eq. 7.20)

Choice of Annual or Monthly Cycle Options

CRM is based on repeating the *SIM/SIMD* simulation with many sequences of naturalized flows and net evaporation rates, starting each simulation with the same initial storage condition. The *CR* record that activates the CRM mode of simulation is the only *SIM/SIMD* record associated with conditional reliability modeling. The annual cycle and monthly cycle options are set by the *CR* record entries listed in Table 7.1.

With the annual cycle option, each hydrologic sequence begins in the same month and extends across the same sequence of months. Thus, with the annual cycle option, the multiple simulations all reflect the same seasonal sequencing. The annual cycle option has the advantage of capturing seasonality, but the disadvantage of limiting the number of simulations to the number of years in the total period-of-analysis or fewer. The monthly cycle option allows up to 12 times more simulations than the annual cycle option. The accuracy of reliability estimates depends both on properly modeling seasonal characteristics of hydrology and maximizing the number of hydrologic sequences used in the CRM analysis. The choice of which option to adopt for a particular application depends upon the relative importance of these two considerations.

Choice of Relative Frequency or Log-Normal Probability Distribution Function

The *2FRE* record frequency options allow application of the log-normal or normal probability distributions to monthly values of the random variable of interest for either non-CRM or CRM applications of frequency analysis. However, these generic *2FRE* frequency options are conceptually different than the CRM methodology for which natural flow volume over a specified time period is the random variable to which the log-normal distribution is applied.

The log-normal is usually preferable to the normal distribution in modeling stream flow and reservoir storage since negative volumes have zero probability. The log-normal probability distribution provides additional information for modeling flow and storage volumes compared to relative frequency, assuming the volumes are actually log-normally distributed. Relative frequency does not presume that the storage or flow volumes are accurately represented by any particular probability function. The Weibull formula is an expression of relative frequency.

In conditional reliability modeling, hydrology may be modeled in *TABLES* with the log-normal probability distribution with or without relating flow probabilities to preceding storage contents. As noted later near the end of the chapter, the incorporation of the log-normal distribution in the CRM probability array methodology may enhance probability estimates over the relative frequency Eq. 7.4, either with or without consideration of storage.

Choice of Equal-Weight or Probability Array Options

All of the hydrologic simulation sequences may be weighted the same in the reliability and frequency analysis computations, or probabilities may be assigned to each simulation sequence that may vary between sequences depending upon preceding storage. The default equal-weight option simplifies the CRM computations and reduces requirements for the model-user to select further sub-options. If the equal-weight option is adopted, the only CRM input is the *SIM/SIMD CR* record. However, the equal-weight option ignores the correlation of natural stream flows and net reservoir evaporation rates to preceding reservoir storage. The probability array approach is designed to incorporate correlation with preceding storage into the assigning of probabilities to the hydrologic sequences. The option also allows modeling of the naturalized flow volumes with the log-normal distribution. Thus, the probabilistic characteristics of river basin hydrology may possibly be estimated more accurately using the probability array option.

The random variable defined in the probability array methodology is naturalized stream flow volume at a single control point or the sum of flows at selected multiple control points. The flow volumes are for a specified length of time. Flow volumes are related to storage volumes in one or more selected reservoirs. Thus, the method is defined in terms of specific locations in the river/reservoir system and specific time periods for aggregating flow volumes. The enhanced accuracy of the probability array option is most applicable if focused on one or a few reservoirs and diversion sites. In this regard, the equal-weight option may be advantageous if many reservoirs and diversion sites scattered over a large river basin are being investigated. For example, in an earlier example, the equal-weight option facilitated the analysis of six reservoirs and diversions at 11 locations at both the end of June and September based on a single execution of *SIM* and *TABLES*. Multiple runs of *TABLES* with CRM parameters varied depending on location and timeframe of interest will typically be required to best achieve the potential enhancements in probability estimation offered by the probability array methodology.

The storage-flow-frequency (SFF) form of the probability array option uses reservoir storage as an index of past hydrologic conditions. Reservoir storage levels reflect cumulative past histories of precipitation, stream flow inflows, evaporation, water demands, and other hydrologic factors. High storage levels result from past wet conditions that are more likely to be followed by continued wet conditions. Severe reservoir draw-downs imply dry weather that may be followed by continued dry conditions. The optional methods in *TABLES* are designed to further improve estimates of the probabilities associated with each of the multiple hydrologic sequences based on the information provided by a known fixed preceding storage condition.

Improvements in probability estimates provided by the probability array option relative to the equal-weight option depend largely on the degree of correlation that exists between preceding storage and naturalized flow volumes. The correlation for a short period will typically be greater than for a longer period. The naturalized flow volume during a month has a greater correlation with reservoir storage at the beginning of the month than the correlation of the flow volume during a year to the storage at the beginning of the year. For typical river systems, the correlation of natural flow to preceding reservoir storage may not necessarily be high. The validity or accuracy of CRM is not highly dependent on there actually being a significant correlation. CRM with the equally-likely option or flow-frequency (FF) relationship option is a valid and useful analysis methodology even with no correlation between stream flow volume and preceding reservoir storage volume. However, if a significant correlation does exist, the modeling the effect of preceding storage on flow probabilities should enhance the CRM analysis.

The correlation coefficients provided by the *5COR* and *5CR1* records provide useful indices for assessing the degree of correlation. Graphical analyses of flow versus storage performed external to the WRAP programs are also useful.

Water availability depends upon both beginning-of-simulation reservoir storage and naturalized stream flow. Beginning reservoir storage is specified by the model-user. If water supply is dominated by releases or withdrawals from storage in a large reservoir, the accuracy of water supply reliability estimates may be relative insensitive to the accuracy of estimates of the probability of naturalized stream flows.

If the equal-weight option is adopted, the discussion stops here. The *TABLES 5CR1* and *5CR2* records are not applicable to the equal-weight option. The remainder of this section addresses options specified on the *5CR1* and *5CR2* records.

SFF or FF Probability Distribution Options

The probability distribution options consist of a set of computational methods in *TABLES* organized into two major tasks controlled by the *5CR1* and *5CR2* records, respectively. The *5CR1* record develops a relationship between exceedance probability and either naturalized flow volume or the flow volume expressed as a percentage of flow computed by a regression equation as defined by Eq. 7.8. These two alternative relationships define the flow-frequency (FF) option and the storage-flow-frequency (SFF) option. The *5CR2* record uses the FF or SFF relationship to build an incremental probability (IP) array assigning probabilities to each of the multiple hydrologic simulation sequences. The incremental probability (IP) array is used by the *2FRE*, *2FRQ*, *2REL*, and *2RES* record routines in their frequency and reliability analysis computations.

The model-user may specify lower and upper limits defining a reservoir storage range on the *5CR1* record. Only those naturalized flow sequences with a preceding storage falling within the specified range are used in building the FF or SFF relationship. Thus, the FF or SFF relationship may be built using only flow sequences that follow storage contents that are reasonably representative of the initial storage that will be considered in the analysis.

With the FF option, the reservoir storage range provides the only mechanism for incorporating storage in the assigning of probabilities to hydrologic sequences. The SFF option is based on the flow ratio (percentage) of Eq. 7.8, which explicitly incorporates preceding storage in the assigning of probabilities. The random variable is naturalized flow volume with the FF option and the Eq. 7.8 flow ratio with the SFF method. Thus, the SFF option is more detailed than the FF option in modeling the correlation between flows and preceding storage. The FF option is applicable if there is little or no correlation. With little correlation between flow and storage, the FF option may still be advantageous over the equal-weight approach by allowing flow volumes over specified time periods to be modeled with the log-normal probability distribution. Again, the correlation of flow volume to preceding storage volume depends upon the length of the time period over which the flows occur. Plots and correlation coefficients provide information that is useful in evaluating the degree of correlation, but choices are based largely on judgment.

Either the FF or SFF relationship may be modeled with either the log-normal probability distribution or Weibull relative frequency equation. The Weibull formula is based on relative frequency which means equally weighting all of the sequences used to develop the FF or SFF relationship. With an extremely large number of hydrologic sequences, the Weibull equation would accurately capture the actual probability distribution of the flow volumes. With a limited sample size, the log-normal distribution provides the advantage of contributing additional information by adopting a probability distribution that reasonably characterizes flow volumes. The log-normal distribution is widely applied in hydrology to model various hydrologic variables including flow volumes. It provides a smooth exceedance frequency curve. The log-normal distribution option is also advantageous over the Weibull probability equation in extrapolating probabilities for flow volumes in the IP array that fall outside the range of volumes used in building the FF or SFF relationship. The Weibull formula may be most applicable for developing a SFF relationship using the monthly cycle option with several hundred sequences. In most other situations, the log-normal distribution is probably preferable.

The sum of naturalized flow volumes at any number of control points covering a defined number of months is correlated with the sum of the preceding reservoir storage volume at any number of control points or in any number of reservoirs. The model-user selects the control points and reservoirs that are most applicable to the particular application. The time period over which flow volumes are defined for purposes of building the SFF or FF relationship and IP array is also user-specified and is not restricted to CR1 on the *CR* record that defines the length of the simulation sequences, though CR1 is the default. The correlation coefficient tables developed using the *5COR* record supplemented by plots developed external to WRAP provide information that is useful in evaluating the degree of correlation related to various alternative choices of time periods and control points. However, these choices are governed largely by logical judgments regarding physical relationships inherent in river basin hydrology. Sensitivity analyses may be performed to evaluate the effects of various options on CRM results.

CHAPTER 8
DETECTING ERRORS AND IRREGULARITES 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 8.1 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 8.1
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 8.3 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 8.2.

Table 8.2
Information Recorded in Message File for Various Values of ICHECK

ICHECK = 0	Trace messages shown in Table 8.3 are written to MSS file. Some error detection routines and most of the warning messages are deactivated.
ICHECK = 1	Table 8.3 trace messages and all error and warning routines are in effect.
ICHECK = 2	Table 8.3 trace messages plus all *UC* and *RF* records are written as read.
ICHECK = 3	Table 8.3 trace messages plus all *CP* records are written as read.
ICHECK = 4	Table 8.3 trace messages plus all *WR* and *IF* records are written as read.
ICHECK = 5	Table 8.3 trace messages plus all *SV* and *SA* records are written as read.
ICHECK = 6	Table 8.3 trace messages plus all *IN* and *EV* records are written as read.
ICHECK = 7	Table 8.3 trace messages plus all *FD*, *FC*, and *WP* records written as read.
ICHECK = 8	Table 8.3 trace messages plus all dual simulation information.
ICHECK = 9	Table 8.3 trace messages and most error checks are in effect.
ICHECK = 10	Trace written to MSS file for conditional reliability modeling showing the sub-division of the hydrologic period-of-analysis into multiple sequences.
ICHECK = 11	Table 8.3 trace messages plus all *RU* records are written as read.
ICHECK = 12	Table 8.3 trace messages plus instream flow targets are recorded.

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 8.3. 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 CRM hydrologic sequences generated by the conditional reliability *CR* record described in the Chapter 7.

Table 8.3
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 8.2. 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 8.2 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 8.2 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.

<u>Error and Warning Messages</u>

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 8.4 and 8.5. Other messages not included in Tables 8.4 and 8.5 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 8.4 and 8.5. *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 8.4
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 8.4 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 8.4 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 DINDEX 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 8.4 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 8.5
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 8.5 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 8.5 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 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 documented by the *Hydrology Manual* 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 8.6 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* ≥ 0) consists of printing the messages shown in Table 8.7 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 8.7 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 8.7 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 8.7 are read and copied correctly.

Table 8.6
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 8.7 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 8.7
Trace Information Copied to Message File for Various Values of ICHECK

ICHECK = 0	Messages shown in Table 8.8; most error detection routines in effect
ICHECK = 1	Messages shown in Table 8.8; all error detection routines in effect
ICHECK = 2	Messages shown in Table 8.8; IN and EV record check
ICHECK = 3	Messages shown in Table 8.8 plus all *CP* records as read
ICHECK = 4	Messages shown in Table 8.8 plus all *AS* records as read
ICHECK = 5	Messages shown in Table 8.8 plus all *SV* and *SA* records as read
ICHECK = 6	Messages shown in Table 8.8 plus all *IN* and *EV* records as read
ICHECK = 7	Messages shown in Table 8.8 plus all *FD*, *FC*, and *WP* records as read

Table 8.8
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 8.9 and 8.10. 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 8.4 and 8.5 are not repeated in Tables 8.9 and 8.10, which show many of the additional *HYD* messages that are not in *SIM*.

Table 8.9
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 8.10
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 *Daily and Salinity Manuals*. *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 8.11 includes all of the messages from preceding lower levels plus additional messages.

Table 8.11
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.

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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.

binary file – The programs *SIM* and *SIMD* record simulation results in an output file with extension OUT which can optionally be in either text or binary format. Files in either format can be read by *TABLES*. The default is for the OUT file to be created as a text file that can be read using text editors such as MS WordPad. The parameter OUTFILE on the *JD* record allows the output OUT file to be created as an unformatted binary file. The binary file has the disadvantage of not being accessible to most editors and the advantages of maintaining the full level of precision of the computed data and reducing computer execution time.

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.

daily modeling system – The WRAP simulation model *SIMD* (*D* for daily) and associated features of *TABLES* allow a sub-monthly computational time step such as daily.

Daily Manual – TWRI Technical Report 340 entitled *Water Rights Analysis Package (WRAP) Daily Modeling System* documents the WRAP programs *SIMD* and *DAY*.

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.

equal weight option – Two alternative strategies can be adopted for assigning probabilities to each of the multiple hydrologic simulation sequences in conditional reliability modeling. The equal-weight option is based on weighting each hydrologic sequence equally. The alternative probability array option assigns probabilities to each hydrologic sequence.

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

flow switch – The flow switch *FS* record inserts a switch in the process of setting an instream flow target or other target each month of the *SIM* simulation based on either the cumulative volume of a specified variable or count of occurrences of meeting a specified criterion.

Fundamentals Manual – TWRI Technical Report 283 entitled *Fundamentals of Water Availability Modeling with WRAP* provides an introductory overview of the basic features of the WRAP programs *WinWRAP*, *SIM*, and *TABLES*.

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

Hydrology Manual – TWRI Technical Report 341 entitled *Water Rights Analysis Package (WRAP) River System Hydrology* documents the WRAP program *HYD* which facilitates developing hydrology input data for the *SIM* simulation model.

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.

probability array option – Two alternative strategies can be adopted for assigning probabilities to each of the multiple hydrologic simulation sequences in conditional reliability modeling. The equal-weight option is based on weighting each hydrologic sequence equally. The alternative probability array option computes probabilities for each hydrologic sequence.

Programming Manual – TWRI Technical Report 388 entitled *Water Rights Analysis Package (WRAP) Programming Manual* provides information regarding the Fortran code of each of the

WRAP programs. The *Programming Manual* facilities maintenance and improvements to the Fortran programs but is not needed to apply the modeling system.

Reference Manual – WRAP is documented by this *Reference Manual* and companion *Users Manual*, *Fundamentals Manual*, *Daily Manual*, *Hydrology Manual*, and *Salinity 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.

Salinity Manual – TWRI Technical Report 317 entitled *Salinity Simulation with WRAP* documents the WRAP program *SALT* and salinity related features of *TABLES*.

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.

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 *Daily 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 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.

type 8 water right – sets a target for use by other rights but performs no other computations.

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 (WRAP) 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 superceded 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* developed during 2004-2008 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
EXAMPLES ILLUSTRATING SIM AND TABLES

Nine examples are provided in this appendix along with the three other examples in Chapters 2 and 3 to illustrate the format and content of *WRAP* datasets. Hypothetical river systems are modeled. Simple rather than realistic numbers are used in these 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*. Essentially any of the types of tables are relevant for any of the *SIM/TABLES* examples. The selection of tables to present with each example was somewhat 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 much larger and more realistic example is presented in the *Fundamentals Manual*. Selected simulation results from the *Fundamentals Manual* example are reproduced in Chapters 5 and 6 of this *Reference Manual* to illustrate particular model features. The CRM examples in Chapter 7 are also derived from the example in the *Fundamentals Manuals*. Likewise, examples in the *Daily* and *Salinity Manuals* are expanded versions of *Fundamentals Manual* example.

The nine examples in Appendix B and three similar examples in chapters 1 and 2 are listed in the table on the next page along with the types of input files and input records included in each example. Input files for the Appendix B examples and the examples in the *Fundamentals*, *Daily*, *Hydrology*, and *Salinity Manuals* are distributed with the software.

<u>SIM and TABLES Examples 1, 2, 3 in Chapters 2 and 3</u>

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 *T1*, *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.

<u>SIM and TABLES Examples in Appendix B</u>

Appendix B consists of Examples 4, 5, 6, 7, 8, 9, 10, 11A, 11B, and 12 illustrating *SIM* and *TABLES*. Examples 4, 5, and 6 provide a general introductory overview of the fundamentals of *SIM* and *TABLES*. Examples 7 through 12 focus on illustrating the following *SIM* modeling features.

Example 7 − target options *TO* record and target series *TS* record
Example 8 − multiple-owner reservoir modeled using *EA*, *EF*, and *AF* records
Example 9 − multiple-reservoir system operations modeled with *OR* records
Examples 10 and 11 − flow switch *FS* and drought index *DI*, *IS*, *IP*, and *IM* records
Example 12 − subordination agreement modeled by combining *PX* and *BU* records

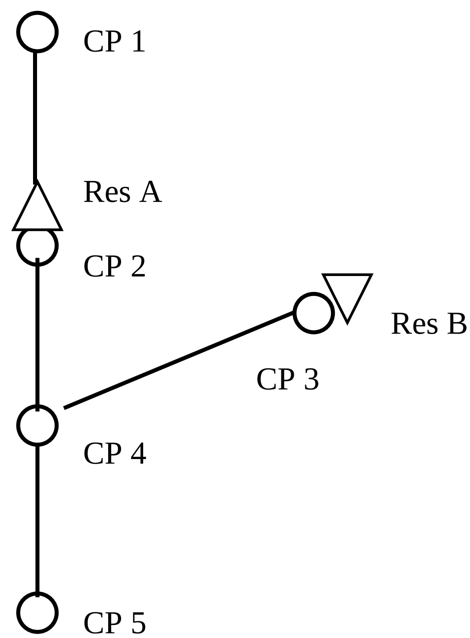
List of Examples

Example	*SIM* Input Files	*SIM* Input Records	*TABLES* Input Records
		SIM and TABLES Examples Presented in Chapters 2 and 3	
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	
		SIM and TABLES Examples Presented in Appendix B	
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	JD,JO,CP,WR,SV,SA,EA, EF,AF,IN,EV	2SWR,2SCP
9	DAT	JD,JO,RO,CP,WR,WS,OR,IN	2DIV,2ROR,2RSD,2RES,4HRR
10	DAT	JD,JO,CP,WR,FS,IN	2TAR, 2DIV, 2REG, IDEN
11	DAT	JD,JO,CP,WR,IF,FS, DI,IS,IP,IM,IN	2FSV, 2FSC, 2REG, IDEN, 2TAR, 2TAR, 2IFT
12	DAT	JD,JO,PX,BU,WR,WS,CP	2TAR,IDEN,2XAV,2DEP

WRAP-SIM and TABLES Example 4

Example 4 illustrates the fundamentals of applying *SIM* and *TABLES*. A system represented by five control points, two reservoirs, seven *WR* record water rights, and an IF record instream flow water right. Drought indices are applied with three of the water rights.

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 following schematic.



System Schematic for Example 4

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.

Water Rights for Example 4

Information for the seven *WR* record 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 Target
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
**
**     ! 1     !   2   !     3 !       4       ! 5     !   6   !     7 !
**345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
**     !       !       !       !       !       !       !       !       !
**
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
**
**       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
**       Water Rights
**
WR  CP-1    1200     irr    1965          0.2               WR-1
**
WR  CP-2                    9999                            WR-2
WS Res A   80000
```

Continuation of WRAP-SIM DAT File for Example 4

```
**
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                     **
**              August 2012 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 DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	VOLUME (%)	+++++++++ PERCENTAGE OF MONTHS +++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	---------- PERCENTAGE OF YEARS ---------- PERCENTAGE OF TARGET DIVERSION AMOUNT 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	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
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	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
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.

(Percentage columns: PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE)

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
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.

(Percentage columns: PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE)

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

CONTROL POINT	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
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.	64759.	65023.	65286.	67822.	74457.	84759.	89790.	93203.	97707.	103203.	120000.	120000.

(Percentage columns: PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE)

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

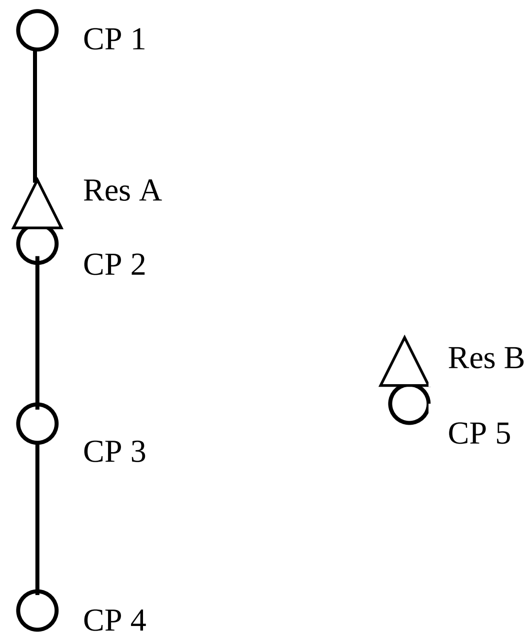
ANNUAL SUMMARY TABLE FOR THE RIVER BASIN

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 STREAMFLOW (AC-FT)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (AC-FT)	UNAPPROPRIATED FLOW (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION 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            20      20      20      20      20      20
**
**  Instream flow requirement IF1 sets a minimmum 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                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 DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	VOLUME (%)	+++++++++ PERCENTAGE OF MONTHS +++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	1%	------- PERCENTAGE OF YEARS ------- PERCENTAGE OF TARGET DIVERSION AMOUNT 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	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	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	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

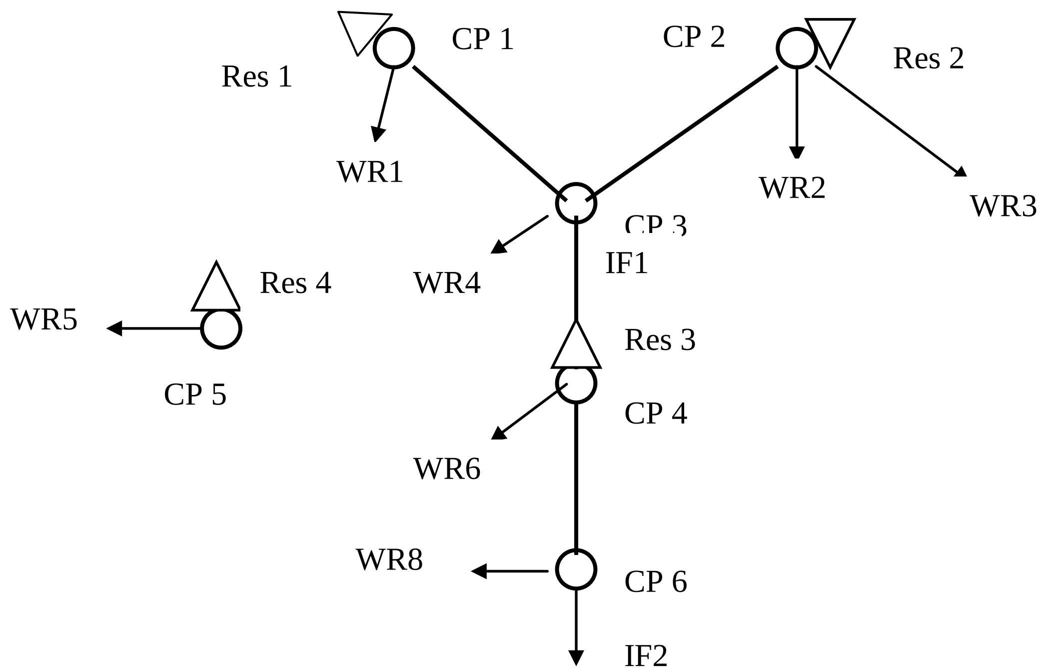
NAME	MEAN STORAGE (AC-FT)	BOTTOM OF ZONE (AC-FT)	TOP OF ZONE (AC-FT)	NUMBER OF PERIODS WITH DRAWDOWNS EQUALING OR EXCEEDING PERCENT OF ZONE STORAGE CAPACITY								
				0%	2%	5%	10%	25%	50%	75%	90%	100%
Res A	365.42	0.	500.	24.	24.	24.	23.	8.	3.	0.	0.	0.
Res B	75.17	0.	100.	24.	12.	12.	12.	10.	8.	0.	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 2008-2009 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^3 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	Primary 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	Capacity at Top of Zone 2
Res1	P	WR1	200	10		
	S	WR4		10	200	200
	S	WR8		10	200	200
Res2	P	WR2	50	25		
	P	WR3	110	25		
	S	WR4		25	250	150
	S	WR8		25	250	125
Res3	P	WR6		30		
	P	WR9	300	30		
	S	WR4		30	300	165
	S	WR5b		150	300	300
	S	WR8		30	300	165
Res4	S	WR5a			200	100
	P	WR5b	200			

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 4.1 (page 108) 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 4.1 reduces to:

area in acres = 0.1 (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 renter 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 on page 113.

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

The release is made from the reservoir with the greatest value for the rank index. The reservoir zones are defined by Figure 4.1 on page 111. 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 2008. 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
**
**     ! 1     !   2   !     3 !       4       ! 5     !   6   !     7 !       8
**345678901234567890123456789012345678901234567890123456789012345678901234567890
**     !       !       !       !       !       !       !       !       !       !
**
JD     2    2008       1      -1      -1
JO     4
XL                                         1.0237
RO     1    RES3
**
**  Monthly Use Factors
**
UC   MUN    0.06    0.06    0.07    0.07    0.08    0.10
UC          0.13    0.12    0.09    0.08    0.08    0.06
UC IRRIG       0       0       0       0    0.25    0.25
UC          0.25    0.25       0       0       0       0
**
**  Control Point Records
**
CP   CP1     CP3
CP   CP2     CP3         0.08333
CP   CP3     CP4                                    NONE
CP   CP4     CP6                                     CP1
CP   CP5     OUT   0.811                             CP1
CP   CP6     OUT                                    NONE
**
**  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    2008      60      60      60      60      60      60      10      10      10      10      10      10
IN   CP1    2009      60      60      60     300     300     300      10      10      10      10      10      10
IN   CP2    2008      20      20      20      20      20      20       0       0       0       0       0       0
IN   CP2    2009      20      20      20     100     100     100       0       0       0       0       0       0
IN   CP3    2008     120     120     120     100     100     100      30      30      30      30      30      30
IN   CP3    2009     120     120     120     500     500     500      30      30      30      30      30      30
IN   CP4    2008     120     120     120     120     120     120      40      40      40      40      40      40
IN   CP4    2009     120     120     120     600     600     600      40      40      40      40      40      40
IN   CP5    2008      74      74      74   12.33   12.33   12.33   12.33   12.33   12.33    92.5    92.5    92.5
IN   CP5    2009      74      74      74   61.67   61.67   61.67   12.33   12.33   12.33    92.5    92.5    92.5
IN   CP6    2008     150     150     150     180     180     180      50      50      50      50      50      50
IN   CP6    2009     150     150     150     900     900     900      50      50      50      50      50      50
**
**  Monthly Net Evaporation-Precipitation Depths
**
EV   CP1    2008      .5      .5      .5      .5      .5      .5      .5      .5      .5      .5      .5      .5
EV   CP1    2009      .5      .5      .5      .5      .5      .5      .5      .5      .5      .5      .5      .5
EV   CP2    2008      6.      6.      6.      6.      6.      6.      6.      6.      6.      6.      6.      6.
EV   CP2    2009      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 DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	PERCENTAGE OF MONTHS WITH DIVERSIONS EQUALING OR EXCEEDING PERCENTAGE OF TARGET DIVERSION AMOUNT 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS 100%	98%	95%	90%	75%	50%	1%
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 TARGET	MEAN SHORTAGE	*RELIABILITY* PERIOD (%)	*RELIABILITY* AMOUNT (%)	PERCENTAGE OF MONTHS WITH ENERGY GENERATION EQUALING OR EXCEEDING PERCENTAGE OF TARGET 100%	95%	90%	75%	50%	25%	1%	PERCENTAGE OF YEARS 100%	98%	95%	90%	75%	50%	1%
RES3	12000.0	3093.51	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	3093.51		74.22														

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
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	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
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	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
CP1	22.4	73.	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.	3.
CP3	25.5	84.	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.	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.
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	MEAN	STANDARD DEVIATION	100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
			PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE											
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
2008	20.	20.	20.	20.	36.	50.	75.	24.	0.	0.	0.	0.	265.
2009	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
2008	0.	0.	0.	14.	19.	67.	0.	11.	0.	0.	0.	0.	112.
2009	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
2008	26.	26.	19.	13.	30.	78.	13.	10.	10.	10.	10.	10.	253.
2009	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
2008	6.	6.	2.	16.	100.	100.	100.	84.	0.	0.	0.	0.	414.
2009	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
2008	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2009	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
2008	48.	48.	44.	88.	60.	60.	10.	10.	53.	23.	23.	23.	491.
2009	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
2008	6.	6.	2.	3.	0.	0.	0.	0.	0.	0.	0.	0.	17.
2009	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
2008	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.	0.	0.	3.
2009	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
2008	6.	6.	2.	3.	0.	0.	0.	0.	0.	0.	0.	0.	17.
2009	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
2008	6.	6.	2.	16.	0.	0.	0.	0.	0.	0.	0.	0.	30.
2009	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
2008	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2009	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.

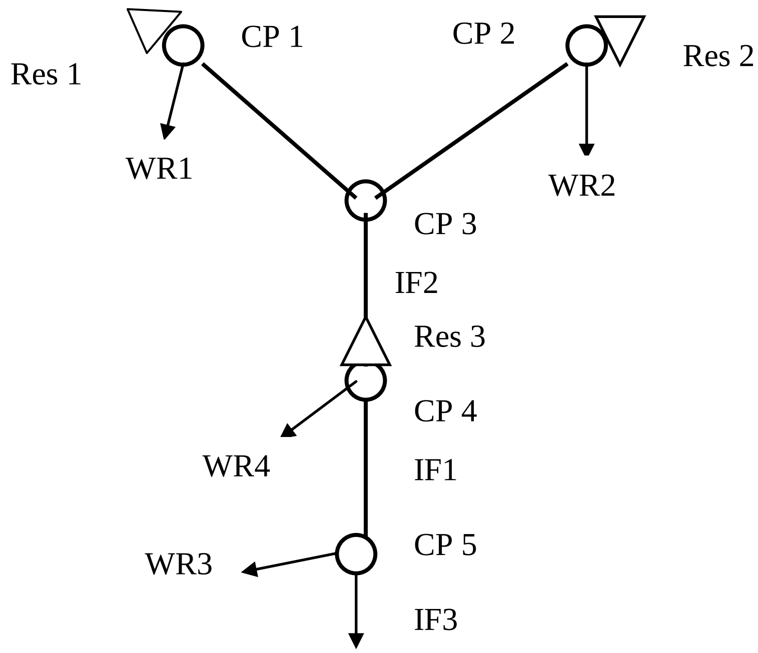
UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP6

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	28.	28.	24.	68.	40.	40.	0.	0.	33.	3.	3.	3.	271.
2009	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
2008 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
2008 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
2008 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
2008 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
2008 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
2008 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
2008 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
2008 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
2008 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
2008 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
2008 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
2008 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
2009 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
2009 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
2009 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
2009 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
2009 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
2009 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
2009 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
2009 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
2009 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
2009 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
2009 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
2009 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 is 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 is 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
**     ! 1     !   2   !     3 !       4      ! 5     !   6   !     7 !       8       ! 9     !  10   !     11 !
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
**      !       !       !       !       !       !       !       !       !       !       !       !       !       !
**
**  Water Right IF1 ---------------------------------------------------------------------------------
IF   CP4                     1900       2                    IF1
TO     1                                      CP4                             CONT
TO     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.     20.
TS          2007    15.     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.
**  -------------------------------------------------------------------------------------------------
**
**      !       !       !       !       !       !       !       !       !       !       !       !       !       !
**3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
**     ! 1     !   2   !     3 !       4      ! 5     !   6   !     7 !       8       ! 9     !  10   !     11 !
**
ED
```

TABLES Output File for Example 7

	NAT CP1	NAT CP2	NAT CP3	NAT CP4	NAT CP5	REG CP1	REG CP2	REG CP3	REG CP4	REG 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 Res 1	STO Res 2	STO Res 3	DIV WR3	DIV WR5	DIV WR6	SHT WR3	SHT WR5	SHT 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 Modeling a 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    2000       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    2000  100000  100000  100000       0       0       0       0       0       0   10000   10000   10000
EV   CP1    2000     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    2001   20000   20000   20000  500000  500000  500000       0       0       0   10000   20000   50000
EV   CP1    2001     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)
2000	1	100000.0	35000.0	500000.0	10000.0	0.0	25000.0	25000.0	0.0
2000	2	100000.0	35000.0	500000.0	10000.0	0.0	25000.0	25000.0	0.0
2000	3	100000.0	35000.0	500000.0	10000.0	0.0	25000.0	25000.0	0.0
2000	4	0.0	0.0	465346.5	9653.5	0.0	25000.0	25000.0	0.0
2000	5	0.0	0.0	431379.3	8967.3	0.0	25000.0	25000.0	0.0
2000	6	0.0	0.0	398084.6	8294.6	0.0	25000.0	25000.0	0.0
2000	7	0.0	0.0	365449.3	7635.3	0.0	25000.0	25000.0	0.0
2000	8	0.0	0.0	333460.2	6989.1	0.0	25000.0	25000.0	0.0
2000	9	0.0	0.0	302104.5	6355.6	0.0	25000.0	25000.0	0.0
2000	10	10000.0	10000.0	281270.8	5833.8	0.0	25000.0	25000.0	0.0
2000	11	10000.0	10000.0	260849.6	5421.2	0.0	25000.0	25000.0	0.0
2000	12	10000.0	10000.0	240832.8	5016.8	0.0	25000.0	25000.0	0.0
2001	1	20000.0	20000.0	224206.8	11626.0	0.0	25000.0	25000.0	0.0
2001	2	20000.0	20000.0	208391.8	10815.0	0.0	25000.0	25000.0	0.0
2001	3	20000.0	20000.0	193348.3	10043.5	0.0	25000.0	25000.0	0.0
2001	4	500000.0	348985.4	500000.0	17333.7	0.0	25000.0	25000.0	0.0
2001	5	500000.0	50000.0	500000.0	25000.0	0.0	25000.0	25000.0	0.0
2001	6	500000.0	50000.0	500000.0	25000.0	0.0	25000.0	25000.0	0.0
2001	7	0.0	0.0	451219.5	23780.5	0.0	25000.0	25000.0	0.0
2001	8	0.0	0.0	404818.5	21400.9	0.0	25000.0	25000.0	0.0
2001	9	0.0	0.0	360681.0	19137.5	0.0	25000.0	25000.0	0.0
2001	10	10000.0	10000.0	328452.7	17228.3	0.0	25000.0	25000.0	0.0
2001	11	20000.0	20000.0	307552.6	15900.1	0.0	25000.0	25000.0	0.0
2001	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    2000       1      -1      -1
JO     3
**
CP   CP1
**       1         2         3         4         5         6         7
**34567890123456789012345678901234567890123456789012345678901234567890l2
**     !       !       !       !       !       !       !       !       !
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    2000  100000  100000  100000       0       0       0       0       0       0   10000   10000   10000
EV   CP1    2000     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    2001   20000   20000   20000  500000  500000  500000       0       0       0   10000   20000   50000
EV   CP1    2001     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 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	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)
2000	1	40000.0	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2000	2	40000.0	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2000	3	40000.0	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2000	4	0.0	0.0	186055.8	3944.2	0.0	10000.0	10000.0	0.0
2000	5	0.0	0.0	172387.7	3668.1	0.0	10000.0	10000.0	0.0
2000	6	0.0	0.0	158990.2	3397.4	0.0	10000.0	10000.0	0.0
2000	7	0.0	0.0	145858.1	3132.1	0.0	10000.0	10000.0	0.0
2000	8	0.0	0.0	132986.0	2872.1	0.0	10000.0	10000.0	0.0
2000	9	0.0	0.0	120368.8	2617.2	0.0	10000.0	10000.0	0.0
2000	10	4000.0	4000.0	111985.5	2383.3	0.0	10000.0	10000.0	0.0
2000	11	4000.0	4000.0	103768.2	2217.3	0.0	10000.0	10000.0	0.0
2000	12	4000.0	4000.0	95713.6	2054.6	0.0	10000.0	10000.0	0.0
2001	1	8000.0	8000.0	88964.4	4749.2	0.0	10000.0	10000.0	0.0
2001	2	8000.0	8000.0	82544.5	4419.9	0.0	10000.0	10000.0	0.0
2001	3	8000.0	8000.0	76437.7	4106.8	0.0	10000.0	10000.0	0.0
2001	4	200000.0	140495.8	200000.0	6933.5	0.0	10000.0	10000.0	0.0
2001	5	200000.0	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
2001	6	200000.0	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
2001	7	0.0	0.0	180198.0	9802.0	0.0	10000.0	10000.0	0.0
2001	8	0.0	0.0	161362.0	8836.0	0.0	10000.0	10000.0	0.0
2001	9	0.0	0.0	143444.8	7917.2	0.0	10000.0	10000.0	0.0
2001	10	4000.0	4000.0	130362.0	7082.8	0.0	10000.0	10000.0	0.0
2001	11	8000.0	8000.0	121877.8	6484.2	0.0	10000.0	10000.0	0.0
2001	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	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)
2000	1	57333.4	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2000	2	57333.4	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2000	3	57333.4	14000.0	200000.0	4000.0	0.0	10000.0	10000.0	0.0
2000	4	0.0	0.0	186111.3	3888.7	0.0	10000.0	10000.0	0.0
2000	5	0.0	0.0	172497.7	3613.6	0.0	10000.0	10000.0	0.0
2000	6	0.0	0.0	159153.6	3344.1	0.0	10000.0	10000.0	0.0
2000	7	0.0	0.0	146073.8	3079.8	0.0	10000.0	10000.0	0.0
2000	8	0.0	0.0	133253.0	2820.8	0.0	10000.0	10000.0	0.0
2000	9	0.0	0.0	120686.0	2566.9	0.0	10000.0	10000.0	0.0
2000	10	4000.0	4000.0	112336.1	2349.9	0.0	10000.0	10000.0	0.0
2000	11	4000.0	4000.0	104151.6	2184.6	0.0	10000.0	10000.0	0.0
2000	12	4000.0	4000.0	96129.1	2022.5	0.0	10000.0	10000.0	0.0
2001	1	8000.0	8000.0	89446.7	4682.3	0.0	10000.0	10000.0	0.0
2001	2	8000.0	8000.0	83090.4	4356.4	0.0	10000.0	10000.0	0.0
2001	3	8000.0	8000.0	77044.1	4046.3	0.0	10000.0	10000.0	0.0
2001	4	239669.6	139889.4	200000.0	6933.5	0.0	10000.0	10000.0	0.0
2001	5	320000.2	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
2001	6	320000.2	20000.0	200000.0	10000.0	0.0	10000.0	10000.0	0.0
2001	7	0.0	0.0	180394.1	9605.9	0.0	10000.0	10000.0	0.0
2001	8	0.0	0.0	161744.5	8649.5	0.0	10000.0	10000.0	0.0
2001	9	0.0	0.0	144004.8	7739.8	0.0	10000.0	10000.0	0.0
2001	10	4000.0	4000.0	131051.5	6953.3	0.0	10000.0	10000.0	0.0
2001	11	8000.0	8000.0	122651.3	6400.2	0.0	10000.0	10000.0	0.0
2001	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	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)
2000	1	72000.0	7000.0	100000.0	2000.0	0.0	5000.0	5000.0	0.0
2000	2	72000.0	7000.0	100000.0	2000.0	0.0	5000.0	5000.0	0.0
2000	3	72000.0	7000.0	100000.0	2000.0	0.0	5000.0	5000.0	0.0
2000	4	0.0	0.0	93179.4	1820.6	0.0	5000.0	5000.0	0.0
2000	5	0.0	0.0	86493.9	1685.5	0.0	5000.0	5000.0	0.0
2000	6	0.0	0.0	79940.8	1553.1	0.0	5000.0	5000.0	0.0
2000	7	0.0	0.0	73517.4	1423.4	0.0	5000.0	5000.0	0.0
2000	8	0.0	0.0	67221.3	1296.2	0.0	5000.0	5000.0	0.0
2000	9	0.0	0.0	61049.8	1171.5	0.0	5000.0	5000.0	0.0
2000	10	2000.0	2000.0	56949.2	1100.6	0.0	5000.0	5000.0	0.0
2000	11	2000.0	2000.0	52929.9	1019.3	0.0	5000.0	5000.0	0.0
2000	12	2000.0	2000.0	48990.1	939.8	0.0	5000.0	5000.0	0.0
2001	1	4000.0	4000.0	45795.6	2194.5	0.0	5000.0	5000.0	0.0
2001	2	4000.0	4000.0	42757.0	2038.7	0.0	5000.0	5000.0	0.0
2001	3	4000.0	4000.0	39866.5	1890.4	0.0	5000.0	5000.0	0.0
2001	4	219614.8	68600.2	100000.0	3466.7	0.0	5000.0	5000.0	0.0
2001	5	460000.0	10000.0	100000.0	5000.0	0.0	5000.0	5000.0	0.0
2001	6	460000.0	10000.0	100000.0	5000.0	0.0	5000.0	5000.0	0.0
2001	7	0.0	0.0	90627.4	4372.6	0.0	5000.0	5000.0	0.0
2001	8	0.0	0.0	81712.0	3915.4	0.0	5000.0	5000.0	0.0
2001	9	0.0	0.0	73231.5	3480.5	0.0	5000.0	5000.0	0.0
2001	10	2000.0	2000.0	67039.2	3192.3	0.0	5000.0	5000.0	0.0
2001	11	4000.0	4000.0	63023.5	3015.7	0.0	5000.0	5000.0	0.0
2001	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	MONTH	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)
2000	1	100000.0	65000.0	65000.0	0.0	35000.0	500000.0	10000.0	25000.0	0.0
2000	2	100000.0	65000.0	65000.0	0.0	35000.0	500000.0	10000.0	25000.0	0.0
2000	3	100000.0	65000.0	65000.0	0.0	35000.0	500000.0	10000.0	25000.0	0.0
2000	4	0.0	0.0	0.0	0.0	0.0	465346.6	9653.5	25000.0	0.0
2000	5	0.0	0.0	0.0	0.0	0.0	431379.2	8967.3	25000.0	0.0
2000	6	0.0	0.0	0.0	0.0	0.0	398084.6	8294.6	25000.0	0.0
2000	7	0.0	0.0	0.0	0.0	0.0	365449.3	7635.3	25000.0	0.0
2000	8	0.0	0.0	0.0	0.0	0.0	333460.2	6989.1	25000.0	0.0
2000	9	0.0	0.0	0.0	0.0	0.0	302104.6	6355.6	25000.0	0.0
2000	10	10000.0	0.0	0.0	0.0	10000.0	281270.8	5833.8	25000.0	0.0
2000	11	10000.0	0.0	0.0	0.0	10000.0	260849.6	5421.2	25000.0	0.0
2000	12	10000.0	0.0	0.0	0.0	10000.0	240832.8	5016.8	25000.0	0.0
2001	1	20000.0	0.0	0.0	0.0	20000.0	224206.8	11626.0	25000.0	0.0
2001	2	20000.0	0.0	0.0	0.0	20000.0	208391.8	10815.0	25000.0	0.0
2001	3	20000.0	0.0	0.0	0.0	20000.0	193348.3	10043.5	25000.0	0.0
2001	4	500000.0	151014.6	151014.6	0.0	348985.4	500000.0	17333.7	25000.0	0.0
2001	5	500000.0	450000.0	450000.0	0.0	50000.0	500000.0	25000.0	25000.0	0.0
2001	6	500000.0	450000.0	450000.0	0.0	50000.0	500000.0	25000.0	25000.0	0.0
2001	7	0.0	0.0	0.0	0.0	0.0	451219.5	23780.5	25000.0	0.0
2001	8	0.0	0.0	0.0	0.0	0.0	404818.6	21400.9	25000.0	0.0
2001	9	0.0	0.0	0.0	0.0	0.0	360681.1	19137.5	25000.0	0.0
2001	10	10000.0	0.0	0.0	0.0	10000.0	328452.7	17228.3	25000.0	0.0
2001	11	20000.0	0.0	0.0	0.0	20000.0	307552.6	15900.1	25000.0	0.0
2001	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 Focusing on Multiple-Reservoir System Operations

The previous Example 6 includes multiple-reservoir system operations along with other features. Example 9 focues specifically on modeling multiple reservoir system operations. Simple numbers are adopted for the example in order to make the computations easy to track in the simulation results. All four of the reservoirs in the example are identical for simplicity.

The four-reservoir system of Example 9 is configured as shown by the schematic of Figure 4.3 in Chapter 4. The example includes a type 2 diversion right located at control point CP-4 in Figure 4.3 that is supplied by releases from the four reservoirs and also a more senior priority type 1 run-of-river diversion right at control point CP-6. The four reservoirs are refilled by separate type 1 water rights.

Each of the four reservoirs is divided into two active pool zones as illustrated in Figure 4.1. Multiple reservoir release decisions are based on Equation 4.2 which is reproduced below.

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

M and A for zones 1 and 2 are four factors entered on the *OR* record. The defaults are 1.0 for the multiplier factor M and 0.0 for the addition factor A.

By default, the storage content in Equation 4.2 is the storage volume of the reservoir at the beginning of the month. The parameter STOFLAG in *JO* record field 6 activates an option in which beginning and ending storage content are averaged for Eq. 4.2 using the *latest* value of end-of-month storage volume. As the simulation is performed for each month, the end-of-month storage volume may change during the course of the computations. Since *JO* record field 6 is blank in this example, beginning-of-month storage content is used in Equation 4.2.

OR records are not required if defaults are adopted for all fields of the record. The defaults of 1.0 and 0.0 for M and A are adopted for each of the four reservoirs in Example 9. However, *OR* records are required for the example to input zone 2 storage and release capacity.

The reservoirs each have a conservation storage capacity of 10,000 acre-feet. For purposes of defining multiple-reservoir release rules, the active conservation pool of each of the reservoirs is divided into two zones (Figure 4.1) of 5,000 acre-feet each. With *WS* record field 7 blank, there is no inactive pool. Releases are constrained to not exceed the release capacity (maximum limit) of 3,000 acre-feet/month.

The *SIM* operating rules allow no reservoir to release from zone 2 unless zone 1 is empty in all four reservoirs. With storage contents extending into zone 1 in one or more reservoirs, the choice of reservoir from which to release from zone 1 in the current month is based on the rank index computed with Equation 4.2 for these reservoirs. The release is made from the reservoir with the highest value for the rank index. Likewise, with contents at or below the top of zone 2 (bottom of zone 1) in all reservoirs, the release is from the reservoir with the highest value for the rank index. The entire release for the month is made from the one selected reservoir unless constrained by the 3,000 acre-feet/month release limit or zone storage contents.

Since *OR* record field 6 is blank (SN2 = 0) for all four reservoirs, releases from the reservoirs are limited to supplying the diversion at control point CP-4 based on gravity flow. The parameter SN2 in *OR* field 6 also provides the alternative option of modeling conveyance through pipeline, canals, and pumping systems with no location constraints. Reservoirs Res-A, Res-B, and Res-C are located upstream of the diversion at control point C-4 and thus reservoir releases are transported by gravity flow from control points CP-1 (reservoir Res-A), CP-2 (reservoir Res-B), and CP-3 (reservoir Res-C) directly to the diversion at control point CP-4. However, reservoir Res-D at control point CP-5 is not located upstream of the diversion at CP-4. With SN2 of 0 in *OR* record field 6, reservoir Res-D is limited to gravity flow releases. Without the senior run-of-river diversion right at CP-6, reservoir Res-D could not participate in the multiple-reservoir system operations.

Although releases from storage are not required, inflows must be passed through reservoirs Res-A, Res-B, and Res-C to meet the requirements of the senior diversion right at control point CP-6. Releases from storage from reservoir Res-D can be made in lieu of passing inflows through reservoirs Res-A, Res-B, and Res-C. Without the SN2 conveyance option activated, this is the only way that reservoir Res-D can contribute to meeting the diversion target of the type 2 diversion right at control point CP-4. Thus, reservoir Res-D is a component of the four reservoir system from this perspective.

The rules defining operations of the four-reservoir system are specified with the *OR* records in the DAT file reproduced below based on equalizing storage draw-downs expressed as a percentage of storage capacity. The objective is to approximately equally balance the storage contents, as a percentage of storage capacity, between the four reservoirs. Each of the four pairs of *WR*/*OR* records contain the following entries.

```
WS Res-A  10000.      0.1       1
OR  CP-2   5000.      1.0     1.0       0     0.0     0.0   3000.
```

The zone 2 storage capacity in each reservoir could be changed from 5,000 acre-feet to zero by revising the *OR* records as follows. This means there is no zone 2.

```
OR  CP-2      0.      1.0     1.0       0     0.0     0.0   3000.
```

With all four *OR* records the same, the multiple-reservoir release decision each month is still based on equally balancing the storage content of the four reservoirs, but the balancing is a little less precise. The non-zero storage capacity of 5,000 acre-feet provides opportunities be split the release between reservoirs in some months. Otherwise, the entire release for a month is from one reservoir, assuming that reservoir is not emptied and the release target does not reach the maximum limit of 3,000 acre-feet/month.

Alternatively, the reservoir operating rules can be based on purposely attempting to maintain storage contents, expressed as a percentage of storage capacity, higher in some reservoirs than in others. For example, the storage capacity of zone 2 of Res-A could be set at 10,000 acre-feet, eliminating zone 1, and at 5,000 acre-feet in the other three reservoirs. No releases would be made from Res-A, which has no zone 1, until zone 1 is emptied in the other three reservoirs. With a little ingenuity, various operating strategies can be modeled by adjusting the zones. The factors M and A in Equation 4.2 provide additional flexibility.

The multiple-reservoir operating rules defined by the *OR* record for determining the release in each month are summarized as follows.

- No release is made from zone 2 of any reservoir as long as water is contained in zone 1 of one or more other reservoirs.
- The release capacity, which is specified to be 3,000 acre-feet/month in this example, is a maximum limit that cannot be exceeded.
- The release in a given month is made from the reservoir with the highest value of the rank index of Equation 4.2. The entire release for the month is from the one selected reservoir unless either the bottom of the storage zone or the release capacity are reached. Two or more reservoirs may release in the same month is and as dictated by these limits.

Other *WRAP-SIM* options for simulating reservoir system operations that are not included Example 9 include the following.

- The multiplier factor M and addition factor A of Equation 4.2 entered on the *OR* record may have values other than the defaults of 1.0 and 0.0. These factors provide additional flexibility for defining the rank index that controls multiple-reservoir release decisions.
- An inactive storage pool may be specified on the *WS* record. The inactive pool has the default of zero in this example. No releases are made from the inactive pool.
- The release capacity of 3,000 acre-feet/month in *OR* record field 9 is a constant in this example. A flow switch *FS* record identifier entered in *OR* record field 10 allows the release limit to vary in accordance with the *FS* record.
- The four default type 1 rights that refill storage in this example fill the reservoirs to a target level of 10,000 acre-feet. Specifying water right type 7 in WR record field 6 allows a variable storage target that is computed by *SIM* each month in accordance with the target setting records which include drought (storage) index *DI*, target options *TO*, supplemental options *SO*, flow switch *FS*, target series *TS*, and backup *BU* records.
- Seasonal rule curve operations can be modeled in lieu of the constant 10,000 acre-feet conservation storage capacity using monthly-varying storage *MS* records.
- Multiple owners of any of the reservoirs can be modeled using the features illustrated in the previous Example 8.

SIM Input DAT File for Example 9

```
T1  SIM DAT File for Example 9 Focused on Multiple-Reservoir System Operations
**
**       1         2         3         4         5         6         7         8
**345678901234567890123456789012345678901234567890123456789012345678901234567890
**      !       !       !       !       !       !       !       !       !       !
JD      2    2008       1      -1      -1
JO      3               1
RO     -1
```

Continuation of SIM Input DAT File for Example 9

```
**
CP  CP-1    CP-2                                        NONE
CP  CP-2    CP-4                                        NONE
CP  CP-3    CP-4                                        NONE
CP  CP-4    CP-6                                        NONE
CP  CP-5    CP-6                                        NONE
CP  CP-6     OUT                                        NONE
**
WR  CP-4   48000           2   2                                Diversion Right
WS Res-A   10000     0.1       1
OR  CP-1    5000     1.0     1.0       0     0.0     0.0   3000.
WS Res-B   10000     0.1       1
OR  CP-2    5000     1.0     1.0       0     0.0     0.0   3000.
WS Res-C   10000     0.1       1
OR  CP-3    5000     1.0     1.0       0     0.0     0.0   3000.
WS Res-D   10000     0.1       1
OR  CP-5    5000     1.0     1.0       0     0.0     0.0   3000.
**
WR  CP-1                   3                                    Refill Storage A
WS Res-A   10000
WR  CP-2                   3                                    Refill Storage B
WS Res-B   10000
WR  CP-3                   3                                    Refill Storage C
WS Res-C   10000
WR  CP-5                   3                                    Refill Storage D
WS Res-D   10000
**
WR  CP-6   24000           1                                    Senior Right
**
**     !       !       !       !       !       !       !       !       !       !
ED
**    !     !     !     !     !     !     !     !     !     !     !     !     !     !
IN  CP-1    2008  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.
IN  CP-2    2008  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.
IN  CP-3    2008  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.
IN  CP-4    2008  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.  3000.
IN  CP-5    2008  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.
IN  CP-6    2008  4000.  4000.  4000.  4000.  4000.  4000.  4000.  4000.  4000.  4000.  4000.  4000.
IN  CP-1    2009     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
IN  CP-2    2009     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
IN  CP-3    2009     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
IN  CP-4    2009     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
IN  CP-5    2009     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
IN  CP-6    2009     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
```

TABLES Input TIN File for Example 9

```
**       1         2         3         4
**  5678901234567890123456789012345678901234567 8
**     !   !   !   !   !   !   !       !       !
2DIV   1   0   0   1   1
IDEN Diversion Right
2ROR   1   0   0   1  -1
2STO   1   0   0   2
2RSD   1   0   0   2
2RES   0   0   4   Res-A   Res-B   Res-C   Res-D
2RES              10000.  10000.  10000.  10000.
4HRR   0   1   1 Diversion Right
ENDF
```

TABLES Output TOU File for Example 9

DIVERSIONS (AC-FT) FOR WATER RIGHT Diversion Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	48000.00
2009	4000.00	4000.00	3000.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11000.00
MEAN	4000.00	4000.00	3500.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	29500.00

RELEASES FROM RESERVOIR (AC-FT) FOR WATER RIGHT Diversion Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2008	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	24000.0
2009	4000.0	4000.0	3000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11000.0
MEAN	3000.0	3000.0	2500.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	17500.0

END-OF-MONTH STORAGE (AC-FT) FOR RESERVOIR Res-A

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2008	8000.0	8000.0	8000.0	7000.0	7000.0	7000.0	6000.0	6000.0	5000.0	5000.0	3000.0	3000.0	6083.3
2009	2000.0	1000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	250.0
MEAN	5000.0	4500.0	4000.0	3500.0	3500.0	3500.0	3000.0	3000.0	2500.0	2500.0	1500.0	1500.0	3166.7

END-OF-MONTH STORAGE (AC-FT) FOR RESERVOIR Res-B

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2008	10000.0	8000.0	8000.0	8000.0	7000.0	7000.0	7000.0	5000.0	5000.0	5000.0	5000.0	3000.0	6500.0
2009	3000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	250.0
MEAN	6500.0	4000.0	4000.0	4000.0	3500.0	3500.0	3500.0	2500.0	2500.0	2500.0	2500.0	1500.0	3375.0

END-OF-MONTH STORAGE (AC-FT) FOR RESERVOIR Res-C

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2008	10000.0	10000.0	8000.0	8000.0	8000.0	6000.0	6000.0	6000.0	6000.0	5000.0	5000.0	5000.0	6916.7
2009	2000.0	2000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	333.3
MEAN	6000.0	6000.0	4000.0	4000.0	4000.0	3000.0	3000.0	3000.0	3000.0	2500.0	2500.0	2500.0	3625.0

END-OF-MONTH STORAGE (AC-FT) FOR RESERVOIR Res-D

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2008	10000.0	10000.0	10000.0	9000.0	8000.0	8000.0	7000.0	7000.0	6000.0	5000.0	5000.0	5000.0	7500.0
2009	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0
MEAN	7500.0	7500.0	7500.0	7000.0	6500.0	6500.0	6000.0	6000.0	5500.0	5000.0	5000.0	5000.0	6250.0

STORAGE DRAWDOWN (AC-FT) FOR RESERVOIR Res-A

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2008	2000.0	2000.0	2000.0	3000.0	3000.0	3000.0	4000.0	4000.0	5000.0	5000.0	7000.0	7000.0	47000.0
2009	8000.0	9000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	117000.0
MEAN	5000.0	5500.0	6000.0	6500.0	6500.0	6500.0	7000.0	7000.0	7500.0	7500.0	8500.0	8500.0	82000.0

STORAGE DRAWDOWN (AC-FT) FOR RESERVOIR Res-B

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2008	0.0	2000.0	2000.0	2000.0	3000.0	3000.0	3000.0	5000.0	5000.0	5000.0	5000.0	7000.0	42000.0
2009	7000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	117000.0
MEAN	3500.0	6000.0	6000.0	6000.0	6500.0	6500.0	6500.0	7500.0	7500.0	7500.0	7500.0	8500.0	79500.0

STORAGE DRAWDOWN (AC-FT) FOR RESERVOIR Res-C

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2008	0.0	0.0	2000.0	2000.0	2000.0	4000.0	4000.0	4000.0	4000.0	5000.0	5000.0	5000.0	37000.0
2009	8000.0	8000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	116000.0
MEAN	4000.0	4000.0	6000.0	6000.0	6000.0	7000.0	7000.0	7000.0	7000.0	7500.0	7500.0	7500.0	76500.0

STORAGE DRAWDOWN (AC-FT) FOR RESERVOIR Res-D

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2008	0.0	0.0	0.0	1000.0	2000.0	2000.0	3000.0	3000.0	4000.0	5000.0	5000.0	5000.0	30000.0
2009	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	60000.0
MEAN	2500.0	2500.0	2500.0	3000.0	3500.0	3500.0	4000.0	4000.0	4500.0	5000.0	5000.0	5000.0	45000.0

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	Res-C	Res-D
2008	1	95.00	80.00	100.00	100.00	100.00
2008	2	90.00	80.00	80.00	100.00	100.00
2008	3	85.00	80.00	80.00	80.00	100.00
2008	4	80.00	70.00	80.00	80.00	90.00
2008	5	75.00	70.00	70.00	80.00	80.00
2008	6	70.00	70.00	70.00	60.00	80.00
2008	7	65.00	60.00	70.00	60.00	70.00
2008	8	60.00	60.00	50.00	60.00	70.00
2008	9	55.00	50.00	50.00	60.00	60.00
2008	10	50.00	50.00	50.00	50.00	50.00
2008	11	45.00	30.00	50.00	50.00	50.00
2008	12	40.00	30.00	30.00	50.00	50.00
2009	1	30.00	20.00	30.00	20.00	50.00
2009	2	20.00	10.00	0.00	20.00	50.00
2009	3	12.50	0.00	0.00	0.00	50.00
2009	4	12.50	0.00	0.00	0.00	50.00
2009	5	12.50	0.00	0.00	0.00	50.00
2009	6	12.50	0.00	0.00	0.00	50.00
2009	7	12.50	0.00	0.00	0.00	50.00
2009	8	12.50	0.00	0.00	0.00	50.00
2009	9	12.50	0.00	0.00	0.00	50.00
2009	10	12.50	0.00	0.00	0.00	50.00
2009	11	12.50	0.00	0.00	0.00	50.00
2009	12	12.50	0.00	0.00	0.00	50.00

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	3166.67	0.	10000.	24.	24.	24.	24.	21.	16.	12.	11.	10.
Res-B	3375.00	0.	10000.	24.	23.	23.	23.	20.	17.	11.	11.	11.
Res-C	3625.00	0.	10000.	24.	22.	22.	22.	19.	15.	12.	10.	10.
Res-D	6250.00	0.	10000.	24.	21.	21.	21.	18.	15.	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	3166.67	0.	10000.	0.0	0.0	0.0	0.0	12.5	41.7	50.0	58.3	100.0
Res-B	3375.00	0.	10000.	4.2	4.2	4.2	4.2	16.7	45.8	54.2	54.2	100.0
Res-C	3625.00	0.	10000.	8.3	8.3	8.3	8.3	20.8	50.0	50.0	58.3	100.0
Res-D	6250.00	0.	10000.	12.5	12.5	12.5	16.7	25.0	100.0	100.0	100.0	100.0

MONTHLY RELEASES FROM SYSTEM RESERVOIRS FOR WATER RIGHT Diversion Right

YEAR	MT	Res-A	Res-B	Res-C	Res-D
2008	1	2000.0	0.0	0.0	0.0
2008	2	0.0	2000.0	0.0	0.0
2008	3	0.0	0.0	2000.0	0.0
2008	4	1000.0	0.0	0.0	1000.0
2008	5	0.0	1000.0	0.0	1000.0
2008	6	0.0	0.0	2000.0	0.0
2008	7	1000.0	0.0	0.0	1000.0
2008	8	0.0	2000.0	0.0	0.0
2008	9	1000.0	0.0	0.0	1000.0
2008	10	0.0	0.0	1000.0	1000.0
2008	11	2000.0	0.0	0.0	0.0
2008	12	0.0	2000.0	0.0	0.0
2009	1	1000.0	0.0	3000.0	0.0
2009	2	1000.0	3000.0	0.0	0.0
2009	3	1000.0	0.0	2000.0	0.0
2009	4	0.0	0.0	0.0	0.0
2009	5	0.0	0.0	0.0	0.0
2009	6	0.0	0.0	0.0	0.0
2009	7	0.0	0.0	0.0	0.0
2009	8	0.0	0.0	0.0	0.0
2009	9	0.0	0.0	0.0	0.0
2009	10	0.0	0.0	0.0	0.0
2009	11	0.0	0.0	0.0	0.0
2009	12	0.0	0.0	0.0	0.0

<u>Example 10 Focusing on Flow Switch *FS* Record Target Setting Capabilities</u>

Examples 10 and 11 illustrate the flow switch *FS* record. The simple system of Example 10 has two control points and one diversion. The diversion at CP-1 is a function of the cumulative regulated flow during the current and preceding 11 months at CP-2. Regulated flow is selected as the flow switch variable *FSV* in *FS* record field 3. 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. Otherwise, the monthly diversion target is 1,000 acre-feet/month.

$$3{,}000 \text{ acre-feet} \leq \text{Cumulative Regulated Flow Volume} \leq 9{,}000 \text{ acre-feet}$$

Inclusion of the current month in the summation of a selected flow switch variable *FSV* is complicated by the fact that *FSV* quantities change during the priority sequence simulation computations. The parameter *FSI(FS,8)* in *FS* record field 15 provides options for including or excluding the current month in the *FSV* summation. *FSI(FS,8)* option 3 consists of simply excluding the current month. *FSI(FS,8)* options 1 and 2 include the current month. Options 1 versus 2 are slightly different if regulated flow is selected as the *FSV* in *FS* field 3 but are identically the same for any other choice of *FSV*. With regulated flow selected for the *FSV*, option 1 differs from option 2 only if the second pass option is activated by *PASS2* in *JO* record field 10 or *IFMETHOD* in *IF* record field 7. With the default *FSI(FS,8)* option 1, during the second pass, the regulated flow computed during the first pass is used. With *FSI(FS,8)* option 2, the latest regulated flow computed in the second pass is used just like for any other *FSV* variable.

FSI(FS,8) options 1 and 2 are the same for Example 10 since the second pass option is not activated. The blank *FS* record field 15 activates the default *FSI(FS,8)* option 1 in which the current month is included along with the 11 preceding months (*FS* record field 12) in totaling the cumulative *FSV* volume. The cumulative *FSV* volume 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 in the example, the naturalized flow is the regulated flow in the current month.

WRAP-SIM Input DAT File for Example 10

```
T1  WRAP-SIM Input File Exam10.DAT
T2  Example 10 from Appendix B of Reference Manual
T3  Illustrating Flow Switch FS Record
JD     4    2007       1      -1      -1
JO     3
CP  CP-1    CP-2                                    NONE
CP  CP-2     OUT                                    NONE
**
WR  CP-1   12000                                                Flow Switch
FS     1    CP-2 0.33333     1.0   3000.   9000.   1   0   0  11
ED
IN  CP-1    2007   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.
IN  CP-2    2007   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.
IN  CP-1    2008      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN  CP-2    2008      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN  CP-1    2009   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.
IN  CP-2    2009   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.
IN  CP-1    2010      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN  CP-2    2010      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
```

TABLES Input TIN File for Example 10

```
COMM  TABLES Input File Exam10.TIN
COMM  Example 10 from Reference Manual
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 10

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT Flow Switch

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	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
2008	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
2009	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
2010	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
2007	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
2008	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
2009	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
2010	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
2007	1000.	1667.	1667.	1667.	1667.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	14667.
2008	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2009	1000.	1667.	1667.	1667.	1667.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	14667.
2010	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
2007	1000.	2667.	4333.	6000.	7667.	8667.	9667.	10667.	11667.	12667.	13667.	14667.	103333.
2008	13667.	12000.	10333.	8667.	7000.	6000.	5000.	4000.	3000.	2000.	1000.	0.	72667.
2009	1000.	2667.	4333.	6000.	7667.	8667.	9667.	10667.	11667.	12667.	13667.	14667.	103333.
2010	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.

Alternative Flow Switch Criteria

The criterion to be applied by a flow switch is selected from three *FSI(FS,2)* options in *FS* field 9. The *FS* record provides two different alternative approaches for applying the *FSV* volume range defined by the lower and upper bounds *FSX(FS,3)* and *FSX(FS,4)* entered in *FS* fields 7 and 8. *FSI(FS,2)* option 1 is based on the total cumulative flow volume. Option 2 is based on counts and combines the count range defined by bounds *FSI(FS,3)* and *FSI(FS,4)* entered in *FS* fields 10 and 11 with the *FSV* volume range defined by *FSX(FS,3)* and *FSX(FS,4)* entered in *FS* fields 7 and 8. The number of months in which the flow volume for the month falls within the specified volume range is counted. The selection between the two multiplier factors depends on whether the count does or does not fall within the count range. The third *FSI(FS,2)* option defines *FSX(FS,3)* and *FSX(FS,4)* differently. With *FSI(FS,2)* option 3, the switch is designed based on whether and to what extent the *FSV* is increasing or decreasing.

Example 10 has one water right which is defined by the following *WS* and *FS* records.

```
WR  CP-1   12000                                                Flow Switch
FS     1     CP-2 0.33333     1.0   3000.   9000.   1   0   0  11
```

The 1,000 acre-feet/month run-of-river diversion target at control point CP-1 is multiplied by a factor of 0.33333 if the summation of regulated flow at control point CP-2 during a 12-month period consisting of the current month and 11 preceding months falls within the following range. Otherwise, the 1,000 acre-feet/month diversion target is multiplied by a factor of 1.0.

$$3{,}000 \text{ acre-feet} \leq \text{Cumulative Regulated Flow Volume} \leq 9{,}000 \text{ acre-feet}$$

The flow switch described above and incorporated into the Example 10 model is based on the total cumulative flow volume occurring during a specified period of time. The alternative criterion is based on counting the number of time steps during the specified time period for which the flow is within a specified range.

Consider the following *FS* record which refers to the following monthly flow volume range.

```
FS      1     CP-2 0.33333     1.0   1500.   2500.   2   3      11
```

$$1{,}500 \text{ acre-feet} \leq \text{Regulated Flow Volume in One Month} \leq 2{,}500 \text{ acre-feet}$$

With this *FS* record, the target is multiplied by a factor of 0.33333 if the regulated flow at CP-2 falls between 1,500 and 2,500 acre-feet/month during at least three of the 12 months of the specified time period. Otherwise, the target is multiplied by the second factor of 1.0. A lower count bound of 3 is entered for *FSI(FS,3)* in *FS* record field 10. With *FS* record field 11 blank, there is no upper bound on the count range.

Consider the following *FS* record which activates *FSI(FS,2)* option 3.

```
FS      1     CP-2 0.33333     1.0     1.0     1.0   3   0       1
```

With this *FS* record, the target is multiplied by a factor of 0.33333 if the regulated flow at CP-2 in the current month exceeds the flow in the preceding month and otherwise by a factor of 1.0.

Example 11A Featuring *FS* and *DI/IS/IP/IM* Record Capabilities

Flow switch *FS* and drought index *DI*, *IS*, *IP*, and *IM* records are featured in Examples 11A and 11B. The *FS* records are used differently in Example 11A than in Example 11B. *FS* records are applied in Example 11A to assess the frequency of meeting certain criteria without actually connecting target setting decisions to the *FS* records. Example 11A illustrates application of WRAP to assess the likelihood or frequency that instream flow targets will be satisfied without activating specific actions in the model to achieve the targets. Conversely, in Example 11B, water management decisions occur within the simulation based on flow switch *FS* record specifications.

Example 11A focuses on developing 2FSV and 2FSC record tables along with other tables that display flow conditions. *FS* record cumulative flow switch variable *FSV* volumes and counts are automatically included on instream flow right output records in the *SIM* output OUT file that is read by the *TABLES* 2FSV and 2FSC record routines. Output records for *WR* record water rights do not. Therefore, *IF* records are used to display the information of interest without actually activating instream flow targets. The *SIM* DAT file and *TABLES* TIN input files are reproduced as follows.

WRAP-SIM Input DAT File for Example 11A

```
T1  WRAP-SIM Input File Exam11A.DAT
T2  Example 11A from Appendix B of Reference Manual
T3  Flow Volumes and Counts Displayed with TABLES 2FSV and 2FSC Records
**       1         2         3         4         5         6         7         8
**345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678
**     !       !       !       !       !       !       !       !       !       !       !
JD     4    2007       1      -1      -1
JO     3                                               2
**
CP  CP-1    CP-2                                    NONE
CP  CP-2     OUT                                    NONE
**
IF  CP-2                      1                     Display FS-1
FS  1  2                          1500.   2500.              11                1
**
IF  CP-2                      2                     Display FS-2
FS  2  2                          1500.   2500.               5   7  12        1
**
WR  CP-2   1200.              3   8                             Type 8 Right
**
IF  CP-2                      4                     Display FS-3
FS  3 10                            50.    300.              11                1 Type 8 Right
**
IF  CP-2                      5                     Display FS-4
FS  4 10                            50.    300.               5   7  12        1 Type 8 Right
**
WR  CP-1   2400.              6                               1       Reservoir
WS Res-A  10000.     0.1     1.0
**     !       !       !       !       !       !       !       !       !       !       !
DI     1       1   Res-A
IS     4     0.0   5000.  10000.
IP           0.0     50.     50.
IM     1  -1  -1  -1  -1  -1  -1  -1  -1   0   0   0
ED
```

WRAP-SIM Input DAT File for Example 11A (Continued)

```
IN  CP-1    2007   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.
IN  CP-2    2007   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.   2000.
IN  CP-1    2008      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN  CP-2    2008      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN  CP-1    2009   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.   1000.
IN  CP-2    2009   1500.   1500.   1500.   1500.   1500.   1500.   1500.   1500.   1500.   1500.   1500.   1500.
IN  CP-1    2010      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
IN  CP-2    2010      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
```

TABLES Input TIN File for Example 11A

```
****     1         2         3
****56789012345678901234567890123456
****   !   !   !   !   !   !   !   !
2NAT   1   0   0   0   1
IDEN    CP-2
2FSV   1   0   0   1   2
IDEN    Display FS-1    Display FS-2
2FSC   1   0   0   1  -2   0
2TAR   1   0   0   1   1
IDEN    Type 8 Right
2FSV   1   0   0   1   2
IDEN    Display FS-3    Display FS-4
2FSC   1   0   0   1  -2   0
2STO   1   0   0   0   1
IDEN    CP-1
2TAR   1   0   0   1   1
IDEN       Reservoir
ENDF
```

The only water right in the DAT file of Example 11A that actually affects water management decisions is the *WR* record right with the identifier *Reservoir*. This water right supplies a diversion target from stream flow at control point CP-1 supplemented as necessary by withdrawals from reservoir Res-A. An intermediate diversion target of 200 acre-feet/month is modified by a drought index defined by a set of *DI*, *IS*, *IP*, and *IM* records. The 200 acre-feet/month target is multiplied by a factor interpolated by *SIM* from the *IS/IP* record table.

The *IM* record specifies that the multiplier factor is set based on the storage contents of Res-A at the beginning of January and is applied during January through September. The drought index is not applied during October, November, and December. Res-A has a storage capacity of 10,000 acre-feet. The monthly diversion target of 200 acre-feet in January through September is multiplied by a factor set based on the storage contents at the beginning of January. The drought index multiplier factor varies linearly from 0.0 to 0.50 as the storage contents increases from 0.0 to 5,000 acre-feet. With storage contents at or above 5,000 acre-feet, the intermediate target of 200 ac-ft/month is multiplied by 0.50 to obtain 100 ac-ft/month. The diversion target during October, November, and December is 200 acre-feet/month. The simulated end-of-month storage contents of Res-A and associated diversion targets are tabulated in the last two tables in the *TABLES* output TOU file reproduced on the following pages.

No instream flow *IF* record targets are activated in the DAT file. Likewise, no *FS* record flow switches are actually activated. The only purpose served by the *IF* and *FS* input records is to record volumes and counts on the instream flow output records in the *SIM* OUT file that are read by the *TABLES* 2FSV and 2FSC record routines. The default (blank) *FS* record field 9 (*FSI(FS,2)* = 0) indicates that the flow switch is not activated. The blank *IF* record field 3 (zero target amount) indicates there is no instream flow target specified.

The flow switch variable *FSV* is selected by in *FS* record field 3. Naturalized flow is the *FSV* for flow switches 1 and 2 connected to the *IF* records with identifiers *Display FS-1* and *Display FS-2*. The diversion target for the *WR* record with water right identifier *Type 8 Right* is the *FS* record flow switch variable *FSV* for flow switches 3 and 4 connected to the *IF* records with identifiers *Display FS-3* and *Display FS-4*.

The *WR* record with the water right identifier *Type 8 Right* has type 8 specified in *WR* record column 36. The only function performed by type 8 rights is to create a target that is used by other water rights. The 100 acre-feet/month diversion target for this *WR* record right is used as the flow switch variable *FSV* for flow switches 3 and 4 connected to the instream flow *IF* record rights *Display FS-3* and *Display FS-4*.

FS record 1 entered with *IF* record right Display FS-1 accumulates naturalized flows at CP-2 over the current month and 11 preceding months. *FS* record 2 entered with *IF* record right Display FS-2 accumulates naturalized flows at CP-2 over the current month and 5 preceding months but only for months 7 through 12 (July, August, September, October, November, and December). Naturalized flows at CP-2 are tabulated in the first table in the *TABLES* output file. The 2FSV tables are the second and third tables in the *TABLES* output TOU file.

FS records 1 and 2 specified a range of naturalized flows defined by lower and upper bounds of 1,500 and 2,500 acre-feet/month. The corresponding 2FSC tables are the 4th and 5th tables in the TOU file. These counts are the number of months during the specified periods that the monthly naturalized flow volume is between 1,500 and 2,500 acre-feet. For example, the 2FSC table for Display FS-1 shows a count of 7 months for May 2008. This means that the naturalized flow is between 1,500 and 2,500 acre-feet during 7 months of the 12-month period extending from June 2007 through May 2008. The 2FSC table for Display FS-2 shows a count of 1 month for May 2008. This means that the naturalized flow is between 1,500 and 2,500 acre-feet during 1 months of the 6-month period extending from December 2007 through May 2008, counting only July, August, September, October, November, and December.

FS record 3 entered with *IF* record right Display FS-3 accumulates diversion targets over the current month and 11 preceding months. *FS* record 4 entered with *IF* record right Display FS-4 accumulates diversion targets over the current month and 5 preceding months but only for months 7 through 12 (July, August, September, October, November, and December). The FSV diversion targets are tabulated in the sixth table in the TOU file. The corresponding 2FSV and 2FSC tables are the 7th, 8th, 9th, and 10th tables in the TOU file. The 2FSC table for Display FS-3 shows a count of 12 months for May 2008. This means that the diversion target for the type 8 *WR* record water right is between 50 and 300 acre-feet during all 12 months of the 12-month period extending from June 2007 through May 2008.

TABLES Output TOU File for Example 11A

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CP-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	24000.
2008	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2009	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	18000.
2010	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	10500.

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT Display FS-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	2000.0	4000.0	6000.0	8000.0	10000.0	12000.0	14000.0	16000.0	18000.0	20000.0	22000.0	24000.0	156000.0
2008	22000.0	20000.0	18000.0	16000.0	14000.0	12000.0	10000.0	8000.0	6000.0	4000.0	2000.0	0.0	132000.0
2009	1500.0	3000.0	4500.0	6000.0	7500.0	9000.0	10500.0	12000.0	13500.0	15000.0	16500.0	18000.0	117000.0
2010	16500.0	15000.0	13500.0	12000.0	10500.0	9000.0	7500.0	6000.0	4500.0	3000.0	1500.0	0.0	99000.0
MEAN	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	126000.0

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT Display FS-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	0.0	0.0	0.0	0.0	0.0	0.0	2000.0	4000.0	6000.0	8000.0	10000.0	12000.0	42000.0
2008	10000.0	8000.0	6000.0	4000.0	2000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30000.0
2009	0.0	0.0	0.0	0.0	0.0	0.0	1500.0	3000.0	4500.0	6000.0	7500.0	9000.0	31500.0
2010	7500.0	6000.0	4500.0	3000.0	1500.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22500.0
MEAN	4375.0	3500.0	2625.0	1750.0	875.0	0.0	875.0	1750.0	2625.0	3500.0	4375.0	5250.0	31500.0

FS RECORD FLOW COUNT FOR WATER RIGHT Display FS-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2008	11.0	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	66.0
2009	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2010	11.0	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	66.0
MEAN	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	72.0

FS RECORD FLOW COUNT FOR WATER RIGHT Display FS-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2008	5.0	4.0	3.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
2009	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2010	5.0	4.0	3.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
MEAN	2.5	2.0	1.5	1.0	0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	18.0

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT Type 8 Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2008	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2009	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2010	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
MEAN	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT Display FS-3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	100.0	200.0	300.0	400.0	500.0	600.0	700.0	800.0	900.0	1000.0	1100.0	1200.0	7800.0
2008	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
2009	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
2010	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
MEAN	925.0	950.0	975.0	1000.0	1025.0	1050.0	1075.0	1100.0	1125.0	1150.0	1175.0	1200.0	12750.0

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT Display FS-4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	0.0	0.0	0.0	0.0	0.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	2100.0
2008	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
2009	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
2010	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
MEAN	375.0	300.0	225.0	150.0	75.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3225.0

FS RECORD FLOW COUNT FOR WATER RIGHT Display FS-3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2008	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
2009	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
2010	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
MEAN	9.2	9.5	9.7	10.0	10.2	10.5	10.7	11.0	11.2	11.5	11.7	12.0	127.5

FS RECORD FLOW COUNT FOR WATER RIGHT Display FS-4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2008	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
2009	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
2010	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
MEAN	3.7	3.0	2.2	1.5	0.7	0.0	1.0	2.0	3.0	4.0	5.0	6.0	32.2

EOP RESERVOIR STORAGE (AC-FT) AT CONTROL POINT CP-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2007	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0
2008	9900.0	9800.0	9700.0	9600.0	9500.0	9400.0	9300.0	9200.0	9100.0	8900.0	8700.0	8500.0	9300.0
2009	9400.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	9950.0
2010	9900.0	9800.0	9700.0	9600.0	9500.0	9400.0	9300.0	9200.0	9100.0	8900.0	8700.0	8500.0	9300.0
MEAN	9800.0	9900.0	9850.0	9800.0	9750.0	9700.0	9650.0	9600.0	9550.0	9450.0	9350.0	9250.0	9637.5

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT Reservoir

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
2008	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
2009	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
2010	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
MEAN	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00

Example 11B Featuring *FS* and *DI/IS/IP/IM* Record Capabilities

Examples 11A and 11B both illustrate the application of the flow switch *FS* records. These two examples use similar datasets with the difference being the purpose served by the *FS* records. Example 11A consists of assessing the extent to which flow switch criteria are satisfied without actually implementing the criteria in water management decisions in the *SIM* simulation. In Example 11B, *FS* records are actually used in setting instream flow targets. Thus, the *FS* records affect water management decisions in the model. Although illustrated here with two different simple examples, these two functions can be combined in the same DAT file in actual applications. A dataset can contain any number of *FS* records used in a variety of ways.

Like the other examples in Appendices B and C, simple rather than relististic numbers are adopted in Examples 11A and 11B. The objective of the examples is to provide input and output datasets that can be easily tracked manually so that users can conveniently explore the computational mechanics of the model.

The *WR* record water right with the identifier *Reservoir* is the same is Example 11B as in Example 11A. The intermediate diversion target of 200 acre-feet/month is modified by a drought index defined by a set of *DI*, *IS*, *IP*, and *IM* records in the same manner in both Examples 11A and 11B as described in Example 11A.

Example 11B includes an additional *WR* record right with the identifier *WR-FS-5*. Drought index 1 defined by the *DI*, *IS*, *IP*, and *IM* records is applied to water right *WR-FS-5* as well as water right *Reservoir*. After adjusting the initial 300 acre-feet/month diversion target using the drought index, the target water right *WR-FS*-5 is then further adjusted using *FS* record flow switch 5. The diversion target is multiplied by either factor *FSX(FS,1)* or *FSX(FS,2)* from *FS* record fields 5 and 6 as designated by the flow switch.

The *WR* record in Examples 11A and 11B with the water right identifier *Type 8 Right* has type 8 specified in *WR* record column 36. The only function performed by type 8 rights is to create a target that is used by other water rights. The 100 acre-feet/month diversion target for this *WR* record right is used as the flow switch variable *FSV* for flow switches 3 and 4 which are components of the instream flow *IF* record rights *Display FS-3* and *Display FS-4*.

Flow switch identifiers are set automatically by *SIM* but can also be entered in *FS* record field 2. In Example 11B, the five flow switch identifiers 1, 2, 3, 4, and 5 are entered in *FS* record column 6 (field 2). Likewise, the identifier 1 for the one drought index is found in *DI* record column 8 (field 2). The identifiers *FSCV(wr)* and *DINDEX(wr)* entered in *WR* record fields 10 and 11 reference the *FS* and *DI* records.

The *FSCV(wr)* of −5 in columns 59-60 of the *WR* record for water right *WR-FS-5* connects flow switch 5 of *IF* record water right *FS*-5 to *WR* record water right *WR-FS-5*. The negative sign means that a flow switch multiplier factor rather than target volume is provided by *FS* record 5. The flow switch multiplier factor previously selected for *IF* record right *IF-FS-5* is applied to the diversion target developed for water right *WR-FS-5*. If the *FSCV(wr)* of −5 is changed to 5, the target previously computed for *IF* record right *IF-FS-5* would be adopted as the diversion target developed for *WR* record water right *WR-FS-5*.

SIM Input DAT File for Example 11B

```
T1  WRAP-SIM Input File Exam11B.DAT
T2  Example 11B from Appendix B of Reference Manual
T3  Application of FS Record Flow Switches and DI/IS/IP/IM Record Drought Index
**       1         2         3         4         5         6         7         8
**3456789012345678901234567890123456789012345678901234567890123456789012345678
**     !       !       !       !       !       !       !       !       !       !       !
JD     4    2007       1      -1      -1
JO     3                                               2
**
CP  CP-1    CP-2                                    NONE
CP  CP-2     OUT                                    NONE
**
IF  CP-2   6000.              1                  IF-FS-1
FS  1  2           1.0      0.0   1500.   2500.   1          11              1
**
IF  CP-2  12000.              2   2              IF-FS-2
FS  2  2           1.0      0.0   1500.   2500.   1           5   7  12       1
**
WR  CP-2   1200.              3   8                            Type 8 Right
**
IF  CP-2  18000.              4   2              IF-FS-3
FS  3 10           1.0      0.0     50.    300.   2   0   1  11              1 Type 8 Right
**
IF  CP-2  24000.              5   2              IF-FS-4
FS  4 10           1.0      0.0     50.    300.   2   0   1   5   7  12       1 Type 8 Right
**
IF  CP-2  30000.              6   2              IF-FS-5
FS  5  1           0.0      1.0     1.0     1.0   3           1              1
**
WR  CP-1   2400.              7                               1       Reservoir
WS Res-A  10000.     0.1     1.0
**
WR  CP-1   3600.              8                          -5   1         WR-FS-5
WS Res-A  10000.
**     !       !       !       !       !       !       !       !       !       !       !
DI     1       1   Res-A
IS     4     0.0   5000.  10000.
IP           0.0     50.     50.
IM     1  -1  -1  -1  -1  -1  -1  -1  -1   0   0   0
ED
IN  CP-1    2007  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.
IN  CP-2    2007  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.  2000.
IN  CP-1    2008     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
IN  CP-2    2008     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
IN  CP-1    2009  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.  1000.
IN  CP-2    2009  1500.  1500.  1500.  1500.  1500.  1500.  1500.  1500.  1500.  1500.  1500.  1500.
IN  CP-1    2010     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
IN  CP-2    2010     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
```

The five instream flow *IF* record rights *IF-FS-1*, *IF-FS-2*, *IF-FS-3*, *IF-FS-4*, and *IF-FS-5* have priorities of 1, 2, 4, 5, and 6, respectively. All five *IF* records set minimum instream flow targets at control point CP-2. *WRNUM(wr,10)* option 2 is entered in column 36 (field 7) of the *IF* records specifying that the largest target is adopted in comparing the alternative minimum instream flow targets. Each of the five *IF* record instream flow rights have a different *FS* record flow switch. The flow switch variable *FSV* (*FS* record field 3) is naturalized flow for *FS* records 1 and 2 and regulated flow for *FS* record 5. The diversion target for the *WR* record with water right identifier *Type 8 Right* is the flow switch variable *FSV* for *FS* records 3 and 4.

The criterion to be applied by a flow switch is selected by specifying one of three *FSI(FS,2)* options in column 52 of the *FS* record. Option 1 is adopted for *FS* records 1 and 2. Option 2 is adopted for *FS* records 3 and 4. Option 3 is adopted for *FS* record 5. The flow switch criteria specified by the five different *FS* records are described as follows.

Two alternative approaches are provided for applying the *FSV* volume range defined by the lower and upper bounds *FSX(FS,3)* and *FSX(FS,4)*. *FSI(FS,2)* option 1 is based on the total cumulative flow volume. Option 2 is based on counts and combines the integer count range defined by bounds *FSI(FS,3)* and *FSI(FS,4)* entered in *FS* fields 10 and 11 with the *FSV* volume range defined by *FSX(FS,3)* and *FSX(FS,4)* entered in *FS* fields 7 and 8. The number of months in which the flow volume for the month falls within the specified volume range is counted. The selection between the two multiplier factors depends on whether the count does or does not fall within the count range. The third *FSI(FS,2)* option defines *FSX(FS,3)* and *FSX(FS,4)* differently. *FSI(FS,2)* option 3 is based on whether and to what extent the *FSV* is increasing or decreasing.

Instream flow right *IF-FS-1* consists of the following *IF* and *FS* records.

```
IF  CP-2   6000.             1                IF-FS-1
FS  1  2           1.0      0.0   1500.   2500.   1          11
```

The flow switch variable *FSV* is the cumulative total naturalized flow volume that occurs at control point CP-2 during the current and preceding 11 months (total of 12 months). The annual target of 6,000 acre-feet is distributed equally to each of the 12 months of the year resulting in an initial monthly instream flow target for each month of 500 acre-feet. In each month of the simulation, the 500 ac-ft target is multiplied by *FSX(FS,1)* of 1.0 if the cumulative naturalized flow falls within the following range and multiplied by *FSX(FS,2)* of 0.0 otherwise.

$$1{,}500 \text{ acre-feet} \leq \text{Cumulative Naturalized Flow Volume} \leq 2{,}500 \text{ acre-feet}$$

The 12 month period includes the current month and preceding 11 months, if there are 11 preceding months. However, prior to December 2007, preceding months number less than 11. Thus, as the current month progresses through the first 12 months (January-December 2007), the flows from January 2007 through the current month are summed. Beginning in December 2007, the summation includes a complete 12 months.

Simulation results recorded by *SIM* in the OUT output file includes cumulative *FSV* volumes and counts for instream flow *IF* record rights. Cumulative *FSV* volumes are organized by *TABLES* as specified by a 2FSV record. The naturalized flow at CP-2 during each month of 2007 and 2009 is 2,000 acre-feet/month. The naturalized flow is zero throughout 2008 and 2010. The 2FSV record table in the *TABLES* output TOU file presented on the following pages shows that the cumulative naturalized flow volume is 2,000 acre-feet in January 2007 increasing by 2,000 each month to 24,000 acre-feet/month in December 2007.

Instream flow right *IF-FS-2* consists of the following *IF* and *FS* records.

```
IF  CP-2  12000.             2   2            IF-FS-2
FS  2  2           1.0      0.0   1500.   2500.   1           5   7  12
```

FS record 2 is a component of *IF* record right *IF-FS-2*. Naturalized flow volumes at control point CP-2 are summed over the current month and 5 preceding months but only for July, August, September, October, November, and December (months 7 through 12). Months 1 through 6 are not included in accumulating the *FSV* volume.

Instream flow rights *IF-FS-3* and *IF-FS*-4 consist of the following *IF* and *FS* records.

```
IF  CP-2  18000.              4   2            IF-FS-3
FS  3 10           1.0      0.0     50.    300.   2   0   1  11              1 Type 8 Right
**
IF  CP-2  24000.              5   2            IF-FS-4
FS  4 10           1.0      0.0     50.    300.   2   0   1   5   7  12       1 Type 8 Right
```

The flow switch variable *FSV* is the diversion target for the type 8 *WR* record water right with identifier *Type 8 Right*.

Instream flow rights *IF-FS-3* and *IF-FS-4* activate *FSI(FS,2)* option 2 in column 52 of the *FS* record. The second flow switch criterion is based on the count of the number of months during the specified period during which the naturalized flow volume falls within the following range.

$$50 \text{ acre-feet} \leq \text{FSV Volume in Each Month} \leq 300 \text{ acre-feet}$$

For right *IF-FS-3*, the current month and preceding 11 months are considered in counting the number of months that the monthly *FSV* volume falls within the specified range. For *IF-FS-4* the period-of-consideration includes the current month and 5 preceding months but only July, August, September, October, November, and December.

The lower and upper count bounds *FSI(FS,3)* and *FSI(FS,3)* are zero and one for both instream flow rights *IF-FS-3* and *IF-FS-4*. The monthly target of 1,500 or 2,000 acre-feet is multiplied by 1.0 if the count of months is 2 or more more and otherwise multiplied by 0.0.

Instream flow right *IF-FS-1* consists of the following *IF* and *FS* records.

```
IF  CP-2  30000.             6   2            IF-FS-5
FS  5  1            0.0      1.0     1.0     1.0   3           1
```

The flow switch is based on whether regulated flow is increasing or decreasing. The *FSV* is the regulated flow at CP-2. *FSI(FS,2)* criterion option 3 is selected in column 52 of the *FS* record which is based on whether:

$$FSX(FS,1) \times (\text{Preceding FSV Volume}) \leq FSX(FS,2) \times (\text{Current Month FSV Volume})$$

In each month of the simulation, the initial instream flow target of 2,500 acre-feet/month is multiplied by 0.0 if the regulated flow in the current month is greater than the regulated flow in the preceding month. Otherwise, the initial 2,500 acre-feet/month target is multiplied by 1.0.

The *SIM* simulation results are presented in the following tables developed with *TABLES*. Tables of the instream flow targets at the completion of the computations in the priority sequence for each of the five *IF* record rights are included in the *TABLES* output TOU file.

TABLES Input TIN File for Example 11B

```
****      1         2         3         4         5         6         7         8
****567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
****    !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !   !
2NAT    1   0   0   0   1
IDEN     CP-2
2REG    1   0   0   0  -1
2FSV    1   0   0   1   2
IDEN          IF-FS-1         IF-FS-2
2FSC    1   0   0   1  -2   0
2TAR    1   0   0   1   1
IDEN     Type 8 Right
2FSV    1   0   0   1   2
IDEN          IF-FS-3         IF-FS-4
2FSC    1   0   0   1  -2   0
2IFT    1   0   0   1   5
IDEN          IF-FS-1         IF-FS-2         IF-FS-3         IF-FS-4         IF-FS-5
2STO    1   0   0   0   1
IDEN     CP-1
2TAR    1   0   0   1   2
IDEN        Reservoir         WR-FS-5
ENDF
```

TABLES Output TOU File for Example 11B

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CP-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	24000.
2008	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2009	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	18000.
2010	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	10500.

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	2000.	24000.
2008	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2009	500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	17000.
2010	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MEAN	625.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	875.	10250.

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT IF-FS-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	2000.0	4000.0	6000.0	8000.0	10000.0	12000.0	14000.0	16000.0	18000.0	20000.0	22000.0	24000.0	156000.0
2008	22000.0	20000.0	18000.0	16000.0	14000.0	12000.0	10000.0	8000.0	6000.0	4000.0	2000.0	0.0	132000.0
2009	1500.0	3000.0	4500.0	6000.0	7500.0	9000.0	10500.0	12000.0	13500.0	15000.0	16500.0	18000.0	117000.0
2010	16500.0	15000.0	13500.0	12000.0	10500.0	9000.0	7500.0	6000.0	4500.0	3000.0	1500.0	0.0	99000.0
MEAN	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	10500.0	126000.0

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT IF-FS-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	0.0	0.0	0.0	0.0	0.0	0.0	2000.0	4000.0	6000.0	8000.0	10000.0	12000.0	42000.0
2008	10000.0	8000.0	6000.0	4000.0	2000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30000.0
2009	0.0	0.0	0.0	0.0	0.0	0.0	1500.0	3000.0	4500.0	6000.0	7500.0	9000.0	31500.0
2010	7500.0	6000.0	4500.0	3000.0	1500.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22500.0
MEAN	4375.0	3500.0	2625.0	1750.0	875.0	0.0	875.0	1750.0	2625.0	3500.0	4375.0	5250.0	31500.0

FS RECORD FLOW COUNT FOR WATER RIGHT IF-FS-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2008	11.0	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	66.0
2009	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2010	11.0	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0	0.0	66.0
MEAN	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	72.0

FS RECORD FLOW COUNT FOR WATER RIGHT IF-FS-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2008	5.0	4.0	3.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
2009	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2010	5.0	4.0	3.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
MEAN	2.5	2.0	1.5	1.0	0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	18.0

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT Type 8 Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2008	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2009	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
2010	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00
MEAN	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	1200.00

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT IF-FS-3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	100.0	200.0	300.0	400.0	500.0	600.0	700.0	800.0	900.0	1000.0	1100.0	1200.0	7800.0
2008	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
2009	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
2010	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0	14400.0
MEAN	925.0	950.0	975.0	1000.0	1025.0	1050.0	1075.0	1100.0	1125.0	1150.0	1175.0	1200.0	12750.0

FS RECORD FLOW ACCUMULATED VOLUMES (AC-FT) FOR WATER RIGHT IF-FS-4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	0.0	0.0	0.0	0.0	0.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	2100.0
2008	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
2009	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
2010	500.0	400.0	300.0	200.0	100.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3600.0
MEAN	375.0	300.0	225.0	150.0	75.0	0.0	100.0	200.0	300.0	400.0	500.0	600.0	3225.0

FS RECORD FLOW COUNT FOR WATER RIGHT IF-FS-3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	78.0
2008	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
2009	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
2010	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	144.0
MEAN	9.2	9.5	9.7	10.0	10.2	10.5	10.7	11.0	11.2	11.5	11.7	12.0	127.5

FS RECORD FLOW COUNT FOR WATER RIGHT IF-FS-4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	21.0
2008	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
2009	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
2010	5.0	4.0	3.0	2.0	1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	36.0
MEAN	3.7	3.0	2.2	1.5	0.7	0.0	1.0	2.0	3.0	4.0	5.0	6.0	32.2

INSTREAM FLOW TARGETS (AC-FT) FOR WATER RIGHT IF-FS-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	500.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00
2008	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	500.00
2009	500.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	500.00
MEAN	250.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	250.00	0.00	500.00

INSTREAM FLOW TARGETS (AC-FT) FOR WATER RIGHT IF-FS-2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	500.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	1500.00
2008	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	1500.00
2009	500.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	1500.00
2010	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	1500.00
MEAN	250.00	0.00	0.00	0.00	500.00	0.00	500.00	0.00	0.00	0.00	250.00	0.00	1500.00

INSTREAM FLOW TARGETS (AC-FT) FOR WATER RIGHT IF-FS-3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	1500.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	2500.00
2008	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	1500.00
2009	500.00	0.00	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	1500.00
2010	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	1500.00
MEAN	500.00	0.00	0.00	0.00	500.00	0.00	500.00	0.00	0.00	0.00	250.00	0.00	1750.00

INSTREAM FLOW TARGETS (AC-FT) FOR WATER RIGHT IF-FS-4

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	0.00	0.00	14000.00
2008	0.00	0.00	0.00	0.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	500.00	0.00	6500.00
2009	500.00	0.00	0.00	0.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	0.00	0.00	6500.00
2010	0.00	0.00	0.00	0.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	500.00	0.00	6500.00
MEAN	625.00	500.00	500.00	500.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	250.00	0.00	8375.00

INSTREAM FLOW TARGETS (AC-FT) FOR WATER RIGHT IF-FS-5

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	2000.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	29500.00
2008	2500.00	0.00	0.00	0.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	500.00	0.00	9000.00
2009	500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	2500.00	28000.00
2010	2500.00	0.00	0.00	0.00	2000.00	2000.00	2000.00	0.00	0.00	0.00	500.00	0.00	9000.00
MEAN	1875.00	1250.00	1250.00	1250.00	2250.00	2250.00	2250.00	1250.00	1250.00	1250.00	1500.00	1250.00	18875.00

EOP RESERVOIR STORAGE (AC-FT) AT CONTROL POINT CP-1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2007	9900.0	9650.0	9400.0	9150.0	8900.0	8650.0	8400.0	8150.0	7900.0	7400.0	6900.0	6400.0	8400.0
2008	6150.0	6050.0	5950.0	5850.0	5750.0	5650.0	5550.0	5450.0	5350.0	5150.0	4950.0	4750.0	5550.0
2009	5655.0	5405.0	5155.0	4905.0	4655.0	4405.0	4155.0	3905.0	3655.0	3155.0	2655.0	2155.0	4155.0
2010	2047.9	2005.2	1962.6	1919.9	1877.2	1834.6	1791.9	1749.2	1706.5	1506.5	1306.5	1106.5	1734.5
MEAN	5938.2	5777.6	5616.9	5456.2	5295.6	5134.9	4974.2	4813.6	4652.9	4302.9	3952.9	3602.9	4959.9

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT Reservoir

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
2008	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1500.00
2009	95.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	1495.00
2010	43.10	42.67	42.67	42.67	42.67	42.67	42.67	42.67	42.67	200.00	200.00	200.00	984.45
MEAN	84.52	85.67	85.67	85.67	85.67	85.67	85.67	85.67	85.67	200.00	200.00	200.00	1369.86

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT WR-FS-5

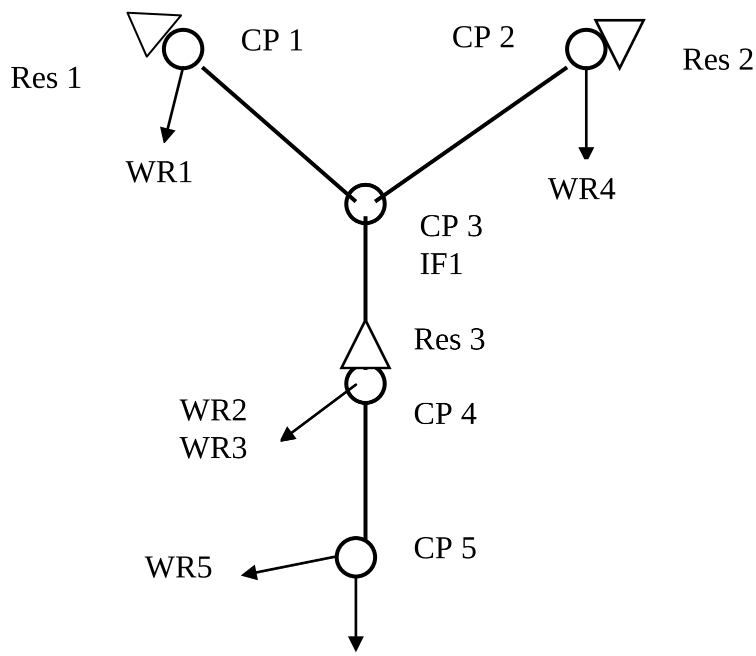
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2007	0.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	300.00	300.00	300.00	2100.00
2008	150.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	150.00
2009	0.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	150.00	300.00	300.00	300.00	2100.00
2010	64.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64.00
MEAN	53.50	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	150.00	150.00	150.00	1103.50

Beginning of Flow Switch Table in SIM Message File for Example 11B

2007	1	IF-FS-1	FS	1	Bounds=	1500.0	2500.0	FSV=	2000.0	Count=	1	Target=	500.0
2007	1	IF-FS-2	FS	2	Bounds=	1500.0	2500.0	FSV=	0.0	Count=	0	Target=	0.0
2007	1	IF-FS-3	FS	3	Bounds=	50.0	300.0	FSV=	100.0	Count=	1	Target=	1500.0
2007	1	IF-FS-4	FS	4	Bounds=	50.0	300.0	FSV=	0.0	Count=	0	Target=	2000.0
2007	1	IF-FS-5	FS	5	Bounds=	1.0	1.0	FSV=	2000.0	Count=	0	Target=	0.0
2007	2	IF-FS-1	FS	1	Bounds=	1500.0	2500.0	FSV=	4000.0	Count=	2	Target=	0.0
2007	2	IF-FS-2	FS	2	Bounds=	1500.0	2500.0	FSV=	0.0	Count=	0	Target=	0.0
2007	2	IF-FS-3	FS	3	Bounds=	50.0	300.0	FSV=	200.0	Count=	2	Target=	0.0
2007	2	IF-FS-4	FS	4	Bounds=	50.0	300.0	FSV=	0.0	Count=	0	Target=	2000.0
2007	2	IF-FS-5	FS	5	Bounds=	1.0	1.0	FSV=	4000.0	Count=	0	Target=	2500.0
2007	3	IF-FS-1	FS	1	Bounds=	1500.0	2500.0	FSV=	6000.0	Count=	3	Target=	0.0
2007	3	IF-FS-2	FS	2	Bounds=	1500.0	2500.0	FSV=	0.0	Count=	0	Target=	0.0
2007	3	IF-FS-3	FS	3	Bounds=	50.0	300.0	FSV=	300.0	Count=	3	Target=	0.0
2007	3	IF-FS-4	FS	4	Bounds=	50.0	300.0	FSV=	0.0	Count=	0	Target=	2000.0
2007	3	IF-FS-5	FS	5	Bounds=	1.0	1.0	FSV=	4000.0	Count=	0	Target=	2500.0
2007	4	IF-FS-1	FS	1	Bounds=	1500.0	2500.0	FSV=	8000.0	Count=	4	Target=	0.0
2007	4	IF-FS-2	FS	2	Bounds=	1500.0	2500.0	FSV=	0.0	Count=	0	Target=	0.0

Example 12 Featuring a Subordination Agreement

Example 12 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 12 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 12

WRAP-SIM Input DAT File for Example 12

```
T1  WRAP-SIM Input File Exam12.DAT
T2  Example 12 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    2009       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 12

```
**  WRAP-SIM Input File Exam12.FLO
**  Example 12 from Appendix B of Reference Manual
**
**  Naturalized Streamflow
**
IN   CP1    2009     600     600     600     600     600     600     600     600     600     600     600     600
IN   CP2    2009     300     300     300     300     300     300     300     300     300     300     300     300
IN   CP3    2009     900     900     900     900     900     900    1200    1200    1200    1200    1200    1200
IN   CP4    2009    1000    1000    1000     900     900     900    1200    1200    1200    1200    1200    1200
IN   CP5    2009    1400    1400    1400    1400    1400     900    1600    1600    1600    2000    2000    2000
IN   CP1    2010    4000    4000    4000       0       0       0     200     200     200    4000    4000    4000
IN   CP2    2010    4000    4000    4000     300     300     300     300     300     300     300     300     300
IN   CP3    2010    4000    8000    8000     500     500     500     500     500     500    4300    4400    5000
IN   CP4    2010    4000    8000    8000     500     500     500     500     500     500     500     500     500
IN   CP5    2010    5000    9000    8000     900     900     900     900     500     500    1000    3000    5000
```

WRAP-SIM Message MSS File for Example 12

```
  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 (2009).
 *** 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
2009   500.0   500.0   500.0   500.0   500.0   500.0   500.0   500.0   500.0   500.0   500.0   500.0
2010   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 (2009).
 *** 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 12

```
COMM  TABLES Input File Exam10.TIN
COMM  Example 10 from Appendix B of Reference Manual
**       1         2         3         4         5
**  5678901234567890123456789012345678901234567890123456789012
**     !   !   !   !   !   !   !   !   !   !   !   !
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 12

DIVERSION TARGETS (AC-FT) FOR WATER RIGHT WR1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
2009	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
2010	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
2009	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
2010	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
2009	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
2010	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
2009	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
2010	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
2009	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
2010	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
2009	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
2010	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
2009	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
2010	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
2009	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
2010	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
2009	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
2010	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
2009	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
2010	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
2009	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
2010	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
2009	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
2010	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