

TR-146

**WATER RIGHTS ANALYSIS PACKAGE (WRAP)  
MODEL DESCRIPTION AND USERS MANUAL**

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**OCTOBER 1996**

RESEARCH PROJECT COMPLETION REPORT

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MODEL DESCRIPTION AND USERS MANUAL**

Project Number - 06

(September 1, 1986 - August 31, 1988)

Grant Numbers

14-08-0001-G1254

14-08-0001-G1451

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The research on which this report is based was financed in part by the Department of the Interior, U.S. Geological Survey, through the Texas Water Resources Institute. Non-Federal matching funds were provided by the Brazos River Authority. The research was also financed in part by the Texas Advanced Technology Program administered by the Texas Higher Education Coordinating Board.

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Technical Report No. 146  
Texas Water Resources Institute  
Texas A&M University  
College Station, Texas 77843-2128

March 1993  
Revised October 1996

## **PREFACE**

The evolution of the Water Rights Analysis Package (WRAP) is outlined in the "*Model Development Background*" section of *Chapter 1* of this report. The model was developed in conjunction with a series of university research projects sponsored by the Texas Water Resources Institute, U.S. Geological Survey, Brazos River Authority, Texas Advanced Technology Program, Texas Water Development Board, and Texas Natural Resource Conservation Commission. W. Brian Walls, David D. Dunn, Anil R. Yerramreddy, and Gerardo Sanchez-Torres addressed various aspects of model development and application in their thesis and dissertation research as graduate students in the Civil Engineering Department at Texas A&M University.

The revised October 1996 as well as the original March 1993 editions of this report document a modeling package consisting of three computer programs called WRAP2, WRAP3, and TABLES. The October 1996 edition of the software and documentation reflect the following revisions to the March 1993 version.

- A watershed flow option has been added to WRAP2 and WRAP3 to supplement the control point approach for defining the location of system components and inputting naturalized

streamflows. Flows at water right locations are computed as a function of the flows at control points provided as input. A flexible methodology is incorporated in the model that allows streamflows at water rights sites to be expressed as a function of control point flows optionally using information ranging from simple drainage area ratios to more complex relationships.

- Dimension limits were changed to increase the maximum number of control points from 50 to 200. The maximum number of water rights and reservoirs was decreased from 2,000 to 1,700. The new watershed flow option allows up to 200 water rights sites in addition to the control point locations. Any of the dimension limits can be easily changed in the future as needed for particular applications.
- Minor revisions to program TABLES include adding means in most of the tables and refining several headings.
- Numerous minor refinements were made throughout this report to update or clarify the presentation.
- “*Appendix G: Guidelines for Developing WRAP Input*” is a new addition to the report.

### **Disclaimer**

All interested persons are welcome to use the WRAP model. The software can be freely copied. However, the computer modeling package must be used at the user’s own risk. Conceptual mistakes, fortran coding errors, data inaccuracies, and misinterpretation of results are always possible with any computer model. The authors of this report, their employers, and the research sponsors assume no responsibility for model accuracy, results, or usage.

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## CHAPTER 1 INTRODUCTION

The Water Rights Analysis Package (WRAP) simulates management and use of the water resources of a river basin, or multiple-basin region, under a priority-based water allocation system. Development of the model was motivated by the Texas water rights system, but it can be applied elsewhere as well. The public-domain software package is generalized for application in any river basin, with input files being developed for the particular river/reservoir/use system of concern. An executable version of the software is available for MS-DOS based microcomputers, and the FORTRAN77 programs have been run on other types of computer systems as well.

The simulation model performs sequential monthly water volume accounting computations. Specified constant annual water use requirements, which vary over the 12 months of the year, are combined with sequences of streamflows and reservoir evaporation rates representing historical hydrology. For each month of the simulation, water rights requirements are met in priority order. Water rights may include diversions, reservoir storage, instream flows, return flows, and hydroelectric power generation. Multiple-reservoir system operations are based on balancing the percentage full of specified zones in the reservoirs included in the system for particular water rights. Simulation results are summarized by a variety of user-specified tables and reliability indices.

### **Report Scope and Organization**

The Water Rights Analysis Package (WRAP) includes three computer programs, called WRAP2, WRAP3, and TABLES, which are documented by this report. Other versions of the programs are briefly noted in the "*Model Development Background*" section on the following pages. A river/reservoir/rights system simulation may be performed with either WRAP2 or WRAP3. The program TABLES performs various manipulations of WRAP2 and WRAP3 input and output files, including developing tables which organize and display simulation results.

This report describes the WRAP package (WRAP2, WRAP3, and TABLES) and provides instructions for its use. The main report and seven appendices are organized as follows. The main report is a general discussion of WRAP capabilities, computational procedures, input data requirements, and simulation output. Appendices A and B provide instructions to be followed by the user in developing input data files. A simple example is presented in Appendix C to illustrate the format of input and output data. Development of the information required for a WRAP input file is outlined in Appendix G. The variables and subroutines incorporated in WRAP2, WRAP3, and TABLES are defined in Appendices D, E, and F, respectively. The main report and Appendices A, B are essential, and Appendices C and G are useful, for applying the model. The information provided by Appendices D, E, and F is useful for anyone interested in examining the Fortran code, but is not needed to use the executable programs.

### **Water Rights**

Generally, in the United States, legal rights to the use of streamflow are based on two alternative doctrines, riparian and prior appropriation. The basic concept of the riparian doctrine is that water rights are incidental to the ownership of land adjacent to a stream. In a prior appropriation system, water rights are not inherent in land ownership, and priorities are established by the dates that users

first appropriate water. The prior appropriation doctrine is based on protecting the rights of senior users from later appropriators. Water law in 29 eastern states is based strictly on the riparian doctrine. Nine western states have a pure prior appropriation system. Ten western states, including Texas, originally recognized riparian rights but later converted to a system of appropriation while preserving existing riparian rights. Two other states also have hybrid systems incorporating the two doctrines in a somewhat different manner (Getches 1990 and Rice and White 1987).

WRAP is a flexible generalized computer model for simulating surface water management, which can be adapted to a broad range of applications, which do not necessarily have to involve water rights or any particular type of water rights system. However, the model is designed specifically to facilitate incorporation of a water rights priority system, such as the prior appropriation permit systems common in the western states, in river basin and reservoir system modeling.

Development of WRAP was motivated by the implementation of a permit system in Texas during the 1970's and 1980's. Surface water law in Texas evolved historically over several centuries. 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 effect transition to the permit system was initiated in 1967 and was essentially completed in 1987. Modeling and analysis of water rights has become an important aspect of water resources development and management in Texas, as well as in other states (Wurbs 1995).

### **Model Development Background**

#### **Earlier Versions of WRAP Programs**

A university research project, entitled "*Optimizing Reservoir Operations in Texas*," was performed in 1986-1988 as a part of the cooperative research program of the Texas Water Resources Institute and U.S. Geological Survey. The Brazos River Authority also participated in sponsoring the project. The research focused on developing improved modeling capabilities for analyzing hydrologic and institutional water availability and for formulating and evaluating management strategies for increasing reservoir yields. A system of 12 reservoirs in the Brazos River Basin, operated by the U.S. Army Corps of Engineers and Brazos River Authority, provided a case study. Several existing generalized 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).

WRAP2, WRAP3, and TABLES were developed during 1990-1993, as part of a Texas Advanced Technology Program research project entitled "*Natural Salt Pollution and Reservoir System Yield*." Development of the revised WRAP, particularly WRAP3 and TABLES, involved essentially coding completely new computer programs. The model was expanded particularly in regard to (1) organization and presentation of the voluminous simulation output data and (2) modeling a comprehensive range of multiple-reservoir, multiple-purpose system operating strategies. Model development and application to the Brazos River Basin are described by Dunn (1993). The WRAP2, WRAP3,

and TABLES package was documented by the March 1993 version of this users manual.

The original TAMUWRAP was replaced by WRAP2 and TABLES. The combined WRAP2 and TABLES represent an improved version of the original model, which provides essentially the same basic modeling capabilities. The computational algorithms were refined, some additional capabilities added, the input data format changed, and the output format totally restructured. WRAP3 is more complex than WRAP2 and provides expanded capabilities for simulating multiple-reservoir, multiple-purpose reservoir system operations. A WRAP2 input data file can also be run with WRAP3. However, a WRAP3 input file may specify optional capabilities which cannot be provided by WRAP2. TABLES can be used with either WRAP2 or WRAP3.

In both the earlier and more recent studies cited above, TAMUWRAP or WRAP was applied to the Brazos River Basin. The 45,600 square mile Brazos River Basin extends from eastern New Mexico southeasterly across the state of Texas to the Gulf of Mexico. Although the studies focused on a particular system of 12 major reservoirs, the entire basin was treated as an integrated system to reflect the interactions and impacts of the many water users. About 1,040 public agencies, cities, private companies, and individual citizens hold over 1,300 permits to use the waters of the Brazos River and tributaries. The water rights include diversions totalling 2,178,000 acre-feet/year and storage capacities totalling 4,567,000 acre-feet in 598 reservoirs. Municipal, industrial, irrigation, mining, and recreation uses account for 51%, 29%, 19%, 1%, and 0.1% of the permitted diversions. The two hydroelectric power plants on the Brazos River have no priority water rights. The studies utilized naturalized monthly streamflows at 20 gage locations covering the 1,020-month period from January 1900 to December 1984.

### WRAPNET and WRAPSALT

Two other more recently developed versions of the model, WRAPNET based on network flow programming and WRAPSALT incorporating salinity considerations, are briefly noted below but are not otherwise included in this report.

WRAPNET was developed in conjunction with a research study to evaluate the advantages and disadvantages of network flow programming as compared to conventional simulation (Yerramreddy 1993; Yerramreddy and Wurbs 1996). Although network flow programming was demonstrated to be a viable alternative modeling approach, conventional simulation was concluded to be advantageous for the WRAP model. 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 the conventional WRAP2 or WRAP3.

Development of WRAPSALT was motivated by natural salt pollution problems in Texas and neighboring states. The model was developed in conjunction with a research project sponsored by the Texas Water Development Board and the cooperative research program of the Texas Water Resources Institute and U.S. Geological Survey (Wurbs et al. 1994; Sanchez-Torres 1994; Wurbs and Sanchez-Torres 1996). WRAPSALT is an expanded version of WRAP3 and TABLES with features added for simulating salt concentrations and associated impacts on water supply reliabilities. Sequences of monthly salt loads are input along with the naturalized streamflows. Diversions are constrained by specified allowable salt concentrations as well as by the quantity of water available.



## October 1996 Revisions

The October 1996 revisions to the WRAP software and this report were accomplished in conjunction with a water availability modeling project for the San Jacinto River Basin performed for the Texas Natural Resource Conservation Commission during August-September 1996 (Wurbs 1996). A watershed flow option was added to WRAP2 and WRAP3 to supplement the control point system of defining the location of system components. Streamflows at remote water right locations in the watersheds above the control points are computed as a function of streamflows at control points. The new watershed flow option, described on pages 33-34, is selected by providing input in field 11 of the water right (WR) records and on the new watershed flow (FL) records.

The dimension limits in WRAP2 and WRAP3 were changed. The maximum number of control points was increased from 50 to 200. The maximum number of water rights and reservoirs was decreased from 2,000 to 1,700.

Minor revisions were also made to program TABLES. Means were added as the last line in most of the tables, and several headings were refined.

Numerous minor editorial refinements were made throughout this report in addition to incorporation of the software revisions noted above. The original version of the new "*Appendix G: Guidelines for Developing WRAP Input*" was developed for the 1996 TNRCC project.

### **Disclaimer**

All interested persons are welcome to use the WRAP model. The software can be freely copied. However, the model must be used at the user's own risk. Conceptual mistakes, fortran coding errors, data inaccuracies, and misinterpretation of results are always possible with any computer model. The authors of this report, their employers, and the research sponsors assume no responsibility for model accuracy, results, or usage.

## CHAPTER 2 MODEL OVERVIEW

### Modeling Capabilities

WRAP is designed for use by water management agencies, consulting firms, and university researchers in performing reservoir/river system water availability and reliability studies. Water availability studies performed to support evaluation of water rights permit applications represent a typical use of WRAP. The model can be applied in various other types of planning and management situations to evaluate alternative water management strategies for specified water use scenarios. Model results can be used to analyze the capability of the river basin to satisfy existing water rights and the amount of unappropriated streamflow remaining for potential additional water rights applicants. Reservoir system simulation studies can be performed to evaluate alternative operating policies or the impacts of adding new reservoirs to a system.

WRAP basically provides an accounting system for tracking inputted streamflow sequences, subject to specified reservoir storage capacities and diversion and instream flow requirements. Water balance computations are performed for each time interval of the overall simulation period. The model provides flexibility for adaptation to a broad range of modeling approaches. Typically, a simulation will be based on the assumptions of (1) a repetition of historical period-of-record hydrology and (2) the full amounts of all permitted diversions are withdrawn as long as water is available from streamflow and/or specified reservoir storage capacity. However, synthetic streamflows, rather than naturalized gaged streamflows, could be used, and various other water use scenarios could be simulated. Although water supply and use systems are viewed in terms of prior appropriation water rights, the model can also be applied to river basins with riparian rights or with water rights not being considered at all. The model is designed for a monthly computational time interval but could be modified for other time intervals such as a day or week. The FORTRAN programs were designed to facilitate adding new features and options as needs arise.

The generalized computer model provides the capabilities for simulating a stream/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. The system configuration is represented in the model by a set of control points. Input data includes: naturalized monthly streamflows at each control point covering the simulation period; control point location, diversion amount, storage capacity, priority date, type use, and return flow specifications for each water right; storage versus area relationship for each reservoir; monthly reservoir evaporation rates; and monthly water use distribution factors for each type of water use. Naturalized streamflows at a water right location can be expressed as a function of flows at control points. The WRAP3 version of the model allows specification of a comprehensive range of reservoir system operating rules and also inclusion of hydroelectric power generation. Flood control aspects of multiple-purpose reservoir system operations can also be included in an approximate manner.

For each month of the simulation, WRAP 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. WRAP computes diversions and diversion shortages associated with each water right. Permitted reservoir capacity is

filled to the extent allowed by available streamflow. Reservoir evaporation is computed and incorporated in the water balance. Return flows are computed as a fraction of diversions and re-enter the stream at user-specified control points. An accounting is maintained of storage levels in each reservoir and streamflow still available at each control point.

WRAP output includes diversions, diversion shortages, hydroelectric energy generated, hydroelectric energy shortages, reservoir storage levels, reservoir evaporation, return flows, streamflow depletions, and unappropriated streamflows for each month of the simulation for each water right or control point. Reliabilities associated with specified water rights can also be tabulated. Simulation results can be organized, tabulated, and summarized in various optional formats.

### **Comparison of Individual Computer Programs**

The Water Rights Analysis Package (WRAP) includes the following FORTRAN77 programs: Water Rights Analysis Program - Version 2 (WRAP2), Water Rights Analysis Program - Version 3 (WRAP3), and TABLES. As previously discussed, the original TAMUWRAP is a single FORTRAN77 program which has been superseded by the combined WRAP2 and TABLES. WRAP2 and TABLES provide the following improvements over the earlier TAMUWRAP: (1) refinements in the computational algorithms, (2) minor modifications in the input data format, and (3) a major restructuring and expansion of the output format.

The computer program TABLES is used with either WRAP2 or WRAP3. TABLES reads WRAP2 or WRAP3 input and/or output data files and writes various user-selected data listings and tables. The simulation input and output data is extremely voluminous. TABLES provides flexible options for organizing and presenting the simulation results.

A stream/reservoir/rights system simulation can be performed with either WRAP2 or WRAP3. However, WRAP3 provides expanded capabilities, not incorporated in WRAP2, related primarily to providing flexibility in modeling a comprehensive range of reservoir system operating strategies and associated system water rights. WRAP2 is limited to simple single-reservoir or run-of-river water rights. Both WRAP2 and WRAP3 are currently dimensioned for a maximum of 1,700 water rights and 1,700 reservoirs. An input data file developed for WRAP2 can also be run with WRAP3. However, a WRAP3 input data file may specify optional capabilities which are not available from WRAP2. The only advantage of WRAP2 over WRAP3 is the relative simplicity of the computer code. The additional capabilities incorporated in WRAP3 result in a significantly different and much more complex computer program. WRAP3 provides the following modeling capabilities which are not included in WRAP2.

1. Whereas WRAP2 allows only one reservoir to be associated with any particular water right, WRAP3 allows multiple-reservoir water rights. A water right diversion can be met by releases from a number of reservoirs and excess streamflows based on user-specified release rules. Both WRAP2 and WRAP3 allow multiple water rights to be associated with the same reservoir.
2. Unlike WRAP2, WRAP3 allows a water right diversion to vary as a function of reservoir storage and/or streamflow.
3. WRAP3 includes hydroelectric power operations; WRAP2 does not.

4. WRAP3 allows an inactive pool (dead storage) to be specified, as well as a two-zone active conservation pool. WRAP2 limits each reservoir to a single active conservation pool, with inactive storage being reflected only in the inputted storage/area relationship used in the evaporation computations.
5. WRAP3 has optional capabilities for handling negative incremental streamflows, which are not provided by WRAP2.
6. WRAP3 allows use of a single input file or optionally a separate hydrology input file for the IN and EV records. WRAP2 uses a single file for all input data.

### **Program Structure, Computer Requirements, and Dimension Limits**

The WRAP programs (WRAP2, WRAP3, and TABLES) are coded in standard Fortran 77. Fortran source codes and executable (compiled) versions of the programs are available on diskette. The subroutines and variables used in the three programs are defined in Appendices D, E, and F. The programs have been compiled and executed on both IBM compatible microcomputers and VAX mini-computers. The programs will run on an IBM compatible microcomputer that has at least 512 kilobytes of random-access memory (RAM) and Microsoft MS-DOS (version 2.1 or greater) or equivalent operating system. The amount of hard disk storage required depends on the size of the input and output data files. The simple example presented in Appendix C can be run without a hard disk. The Brazos River Basin studies cited earlier required about eight megabytes of available hard disk storage.

The programs are batch-oriented. Input data files can be developed using any editor. WRAP2/WRAP3 creates a output file with certain data provided by default and other types of data specified by the user. The model user will normally not be interested in viewing the WRAP2/WRAP3 output file. A WRAP2 or WRAP3 output file is read by TABLES as an input file. TABLES creates user-specified tables for displaying the simulation results. The three programs are compiled and executed as separate programs.

The programs are presently dimensioned for 200 control points, 1,700 water rights, 1,700 reservoirs, 50 reservoir storage-area tables, 200 watershed flow (FL) records, 15 water use types, and 12 periods per year. The number of years in the period-of-analysis is not limited. The dimension statements in the Fortran codes can be easily changed. The model uses a monthly computational time interval but could be modified for another time interval such as a week or day. Any consistent set of units can be used. Inputted multiplier factors associated with the streamflow and evaporation rate input data can be used for unit conversions.

## Glossary

A glossary of selected terms is provided as Table 1. Each of the terms included in Table 1 is defined and discussed in more detail in various parts of this report. The definitions are specifically from the perspective of the use of the terms in this report.

Table 1  
**GLOSSARY**

### WRAP Computer Programs

**TAMUWRAP** - The original version of the model, called the *Texas A&M University Water Rights Analysis Program (TAMUWRAP)*, has been superseded by the other programs noted below.

**WRAP** - The term *Water Rights Analysis Package (WRAP)* refers to the overall set of computer programs. This report documents WRAP2, WRAP3, and TABLES.

**WRAP2** - The *Water Rights Analysis Program-Version 2 (WRAP2)* is the basic simulation model. WRAP2 and TABLES replace the original TAMUWRAP.

**WRAP3** - The *Water Rights Analysis Program-Version 3 (WRAP3)* provides essentially all the capabilities of WRAP2 plus multiple-reservoir system operation, hydroelectric power, and other optional features not available in WRAP2.

**TABLES** - This computer program develops tables and data listings from WRAP2 or WRAP3 input and output files which organize and summarize the simulation results.

**WRAPNET** - Provides the same modeling capabilities as WRAP2, but the internal computations are performed using network flow programming. WRAPNET is not addressed in this report.

**WRAPSALT** - Provides the same modeling capabilities as WRAP3 plus features for considering salinity in assessing water supply reliability. WRAPSALT is not addressed in this report.

### Spatial Configuration of River Basin

**control point** - a modeling mechanism for representing the location of streamflows, reservoirs, diversions, return flows, and other system features. The control point located just downstream of each control point is specified in the input file. Naturalized streamflows are provided as input, and unappropriated flows are computed for each control point.

**watershed flow option** - This WRAP2/WRAP3 option restricts the amount of water available to a water right to naturalized streamflow at its location computed as a function of the naturalized flows input for one or more control points.

### Streamflow Data

**naturalized streamflows** - Historical gaged streamflow data adjusted to remove the impacts of reser-

voir construction, water use, and other human activities are provided for each control point as WRAP input data on inflow (IN) records.

**incremental streamflows** - The naturalized streamflow data represent total or cumulative flows at a control point. The computational algorithms, as well as input and output data, are based on total flows rather than incremental flows. However, WRAP3 includes an option for checking for negative incremental flows. An incremental flow is the difference between total flows at adjacent control points.

**streamflow depletions** - WRAP computed streamflow depletions are the streamflow amounts appropriated to meet water rights diversions and/or refill reservoir storage capacity. Streamflow depletions are associated with a particular water right.

**unappropriated streamflows** - WRAP computed unappropriated flows, associated with a particular control point, are the portions of the naturalized streamflows still remaining after the streamflow depletions are made for all the water rights included in the simulation.

#### Reservoir Evaporation Rates

**gross evaporation rates** - monthly lake surface evaporation rates in inches or feet.

**net evaporation rates** - gross evaporation less the effective rainfall, which is rainfall over the reservoir site less the amount reflected as runoff in the naturalized streamflows. Net rather than gross evaporation rates are typically input on the EV records.

#### Water Rights

**water right** - A water right consists of a permitted annual water diversion amount (or permitted annual hydroelectric energy amount), reservoir storage capacity, control point location, and priority number, along with associated data such as monthly use factors, return flow specifications, watershed flow location, and operating rules for multiple reservoirs which can make releases to satisfy the permitted diversion, hydropower, and reservoir storage targets.

**permitted or authorized diversion** - the target amount of water to be appropriated from streamflow at a control point location and reservoir storage at the same or other locations. Monthly permitted diversion amounts are inputted as an annual diversion amount and set of 12 monthly distribution factors.

**actual diversion** - permitted diversion target limited by water availability.

**shortage** - permitted diversion minus actual diversion.

#### Table 1 Continued

#### **GLOSSARY**

**return flow** - An amount of water computed as the actual 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.

**run-of-river water right** - a water right with zero reservoir storage capacity.

**instream flow requirement** - WRAP contains no variable specifically to denote an instream flow target. Instream flow requirements are specified using a water right permitted diversion with a return flow factor of 1.0.

**priority** - a numerical value included in the input data for a water right indicating the relative seniority of the right. The inputted priority numbers will typically represent seniority dates but could represent any other type of priority indicator. In each period of the simulation, water rights are considered in turn and available water appropriated in order of the priorities.

**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 computations.

### Reliability Indices

**period reliability** - the percentage of the total months (periods) in the overall simulation period-of-analysis during which a specified permitted diversion target (or hydroelectric energy target) is met without shortage.

**volume reliability** - the total volume of actual diversions (or total firm hydroelectric energy generated) during the simulation period-of-analysis expressed as a percentage of the corresponding total permitted diversion or hydroelectric energy targets.

### WRAP3 System Operating Rules

**type 1 water right** - allows a permitted diversion target (or hydroelectric energy target) and/or storage target in one reservoir to be met from streamflow depletions and releases from 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.

### Table 1 Continued **GLOSSARY**

**type 4 water right** - the permitted diversion target is specified as a function of system reservoir storage and naturalized streamflow.

**inactive pool** - the bottom pool of a reservoir from which releases or withdrawals cannot be made

except by evaporation.

**active pool** - reservoir storage pool from which releases and withdrawals are made. An active pool can be divided into two vertical zones for purposes of defining multiple reservoir release rules.

**primary and secondary reservoirs** - Up to 50 reservoirs can be associated with each water right. However, storage capacity can be refilled in only one primary reservoir by each right. The other secondary reservoirs make releases to meet the water right diversion but cannot be refilled by the water right. A secondary reservoir for one water right can be a primary reservoir for another water right.

**permitted firm energy** - inputted hydroelectric energy targets.

**secondary energy** - additional hydroelectric energy, above the permitted firm energy, which could be generated incidentally by releases for more senior water rights diversions, assuming unlimited turbine capacity.

**flood control operation** - Although WRAP was designed for conservation operations with no features included specifically for flood control, flood control reservoir operations can be modeled by combining types 4 & 1 water rights.

#### Time Periods

**computational time interval** - Although WRAP is presently limited to a monthly time interval, the model was designed to facilitate modification for other time intervals such as a week or day.

**hydrologic simulation period** - In a WRAP simulation, specified annual water use requirements are met, subject to water availability, during a hypothetical repetition of historical hydrology represented by sequences of naturalized streamflows and net evaporation rates for each month of a multiple-year hydrologic simulation period, which is also called the period-of-analysis.

#### Input Files

**input data record** - An input record is a line of data, not to exceed 80 characters, in an input data file. Each WRAP input record begins with a two-character record identifier. Each TABLES input record begins with a four-character record identifier.



## **CHAPTER 3**

### **SYSTEM COMPONENTS**

A river basin stream/reservoir/rights system is represented in the model by the following inter-related components: (1) control points, (2) basin hydrology, (3) water rights, (4) reservoirs, (5) return flows, (6) hydroelectric power, and (7) reservoir system operating rules. Actually, reservoirs, return flows, hydroelectric power, and reservoir system operating rules are all subcomponents or features of the water rights component. The characteristics of the model components and subcomponents are represented by the input data.

#### **Control Points**

Control points provide a mechanism to model the locational configuration of the river basin system. Control points are specified in the input data to indicate the location of streamflow data, reservoirs, water rights diversions, and other system features. The computations are based on knowing which of the other control points are located downstream of each control point. Essentially any configuration of stream tributaries, reservoirs, and within-basin or interbasin conveyance facilities can be modeled. Streamflow data must be provided for all control points included in a simulation. Each water right can be assigned a separate control point. Alternatively, water rights can be aggregated such that the water rights assigned to a given control point include all water rights located between that control point and the next adjacent control point. Multiple water rights at the same control point all have access, in priority order, to the streamflow available at the control point as limited by the watershed flow option noted below. Any number of reservoirs can be associated with a single control point, but each control point is limited to one set of reservoir evaporation rates.

Naturalized streamflows are provided as input for all control points, and the model computes unappropriated streamflows and other quantities for each control point. A watershed flow option allows naturalized streamflows at a water right location to be determined as a function of naturalized streamflows at specified control points. The WRAP model limits water available to the water right to the lesser of naturalized flows at the site or unappropriated flows at downstream control points.

#### **Basin Hydrology**

The basin hydrology consists of naturalized streamflows and net reservoir evaporation rates at each control point for each month (time period) of the simulation period-of-analysis. Monthly streamflows and evaporation rates are provided by the user as input data. The model allows streamflows and evaporation rates at a control point to be computed by multiplying data inputted for that location or another location by a user-specified factor. This feature can be used for unit conversion factors and/or for transferring streamflow or evaporation data from one control point location to another. Although any units can be used, typical units are acre-feet/month for streamflows and feet/month for evaporation rates. Normally, the user will input streamflows which have been naturalized to remove the nonhomogeneities caused by the activities of man in the river basin. Net reservoir evaporation rates are normally used, which have been adjusted for precipitation to reflect the change in the precipitation-runoff relationship caused by construction of a reservoir project.

#### **Water Rights**

In the model, a water right is represented by the following input data: (1) a control point location, (2) annual diversion amount, (3) reservoir storage capacity, (4) priority number, (5) type of use, (6) return flow factor, (7) return flow control point location, and (8) optional water right group. As discussed later, WRAP3 also allows specification of (1) multiple-reservoir system operating rules, (2) water rights diversions as a function of reservoir storage and/or naturalized streamflow, and (3) hydro-electric power operating rules. The diversion amount, storage capacity, priority number, and return flow factor may be zero. The model uses the type of use to assign the proper monthly water use distribution factors. A set of 12 monthly factors are provided as input data for each type of use (such as municipal, industrial, irrigation, etc.) to distribute the annual water right diversions over the year. The priority number typically represents dates. For example, a priority date of May 12, 1965 is inputted 19650512, which is a larger number than the priority corresponding to any earlier date. The return flow factor is the fraction of the diversion which is returned to the stream at a user-specified control point.

An actual water right permit may be represented by any number of “model” water rights or sets of values for each of the variables cited above. Also, in certain applications, several water rights may be combined and inputted to the model as a single aggregate water right. The model provides considerable flexibility in describing water rights. However, the total number of rights in the model may be somewhat misleading since a single appropriator holding a single water right permit may have several rights listed representing different components or features of the water right permit. For example, a water right which includes three different uses, such as municipal, industrial, and irrigation, would be treated as three separate water rights, since the monthly water use distribution factors are different for the various uses. A single reservoir may have several water rights with different combinations of priority dates, storage capacities, and other variables. The diversion amount and storage capacity can be assigned different priorities by treating the right as two separate rights, one with zero storage capacity and the other with a zero diversion. As discussed later, a single “system water right” may be represented by a combination of several WRAP3 type 1, type 2, type 3, and/or type 4 water right input data records.

Instream flow requirements are not defined as a separate variable in the computational algorithms of the model. An instream flow requirement is specified in the input data as a water right diversion with an associated return flow factor of 1.0.

### **Reservoirs**

As discussed above, reservoir storage capacity is provided with the water rights input data. Several water rights can be associated with a single reservoir. The storage capacity associated with each water right is the total cumulative capacity to which the reservoir can be refilled under that right or permit, assuming the reservoir has been drawn down in previous months and streamflow is now available for refilling. WRAP3 allows releases from multiple reservoirs to meet the one diversion target and maintain storage in the one reservoir specified by a single water right. WRAP3 includes options for specification of multiple-reservoir release rules and also diversions which are a function of reservoir storage and/or naturalized streamflows.

The storage capacity associated with a water right is defined differently in WRAP2 and WRAP3 in regard to inactive storage. WRAP3 allows the storage level to fall below the top of inactive pool due to evaporation; WRAP2 does not. Otherwise, both versions properly reflect inactive storage even though the approach is somewhat different. In WRAP2, the water right storage capacity is for active

storage only, and the storage versus water surface area input data reflects the effect of the active storage being in addition to inactive storage. In WRAP3, the water right storage capacity includes inactive as well as active storage capacity, and an inactive pool is explicitly designated. The storage capacity is defined exactly the same in WRAP2 and WRAP3 for reservoirs with no inactive pool.

A storage capacity versus water surface area relationship is provided as input data for each reservoir. The storage versus area relationship is used by the model in the evaporation computations. The reservoir evaporation volume for a given month is the computed average water surface area during the month times the appropriate inputted net evaporation rate. Two optional formats are provided for inputting a reservoir storage versus area relationship. A table of storages versus areas can be inputted. The model applies linear interpolation to the table to determine the area corresponding to a previously computed storage. Alternatively, values of the coefficients a, b, and c can be provided as input data for the following equation which is incorporated in the model:

$$A = aS^b + c$$

where S denotes storage and A denotes water surface area.

Any number of water rights can have storage capacity in the same reservoir. For reservoirs with multiple rights, the storage capacity associated with each water right is the cumulative or total capacity. The reservoir can be filled to this level by the water right. Streamflow depletions, diversions, and the other quantities computed for a particular water right represent values assuming no other more junior water rights exist but senior rights do exist. For purposes of 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 water right. However, with the exception of WRAP3 type 4 rights, diversions associated with a water right are met from the total cumulative storage capacity of the right. Thus, a junior water right could empty a reservoir, even though the depleted storage capacity affects water available to a senior right at the same reservoir during the next month. Hydropower rights allow the beginning-of-period and end-of-period storage to exceed the storage capacity of the hydropower right due to other rights at the same reservoir. WRAP3 type 4 rights allow diversions to be specified as a function of reservoir storage.

### **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 conveyance facilities such as canals, pipelines, and pumping plants.

Return flows are computed in the model as a user-specified fraction of 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 tributary. The return flow can also represent an interbasin transfer of water. The control points of origin and destination of the diversion return flow can be located in different river basins. The diversion amount, return flow factor, and return flow control point location are part of the water right input data.

Timing of return flows is also a user-specified option. The return flows may be returned during the same month as the associated 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.

### **Hydroelectric Power (WRAP3)**

Hydroelectric power water rights can be included in a simulation performed with WRAP3, but not WRAP2. A hydroelectric power water right is represented by the following input data: (1) location indicated by control point, (2) annual firm energy target, (3) reservoir storage capacity, (4) priority number, (5) plant efficiency factor, (6) constant tailwater elevation, (7) reservoir storage versus water surface elevation table, and (8) set of 12 monthly distribution factors. The annual firm energy requirement is apportioned to each month of the year in the model using the inputted monthly distribution factors. Hydroelectric power can also be included in the multiple-reservoir system operating rules discussed below.

For each month of the simulation, the firm energy target is met as long as sufficient water is available from streamflow and reservoir storage. An energy shortage occurs if sufficient water is not available to meet the user-specified firm energy requirement. The model also computes a form of secondary (surplus) energy. Secondary energy represents additional energy, above firm energy, 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. The capacity of the power plant is not considered, and thus the secondary energy is based on assuming unlimited capacity. Secondary energy is treated by the model as a “negative” firm energy shortage. No releases from storage or streamflow depletions are made if previous releases for senior rights are sufficient to meet or exceed the firm energy requirement.

### **Reservoir Operating Rules (WRAP2)**

The reservoir operating procedure in WRAP2 is very simple. For a given month, the water right diversion target is met from reservoir inflows and storage as long as sufficient water is still available considering other more senior water rights. A shortage occurs if sufficient water is not available. The reservoir storage capacity associated with the water right is refilled whenever water is available. Each water right is limited to a specified storage capacity in a single reservoir. Of course, a water right can be run-of-river with zero storage capacity.

Multiple rights at the same reservoir allow refilling the reservoir to different levels depending on the priorities of each of the rights. However, the reservoir is treated as a single active conservation pool. There are no zones and no designated inactive (dead storage) pool. The user-inputted storage versus surface area data should be adjusted to reflect inactive storage so that the evaporation is computed correctly.

### **Reservoir System Operating Rules (WRAP3)**

A major difference between WRAP2 and WRAP3 is the comprehensive range of reservoir system operating rules which can be modeled with WRAP3. WRAP3 provides considerable flexibility in modeling complex system operations and associated water rights permits.

Reservoir system operating rules 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 system operating policy and associated water right permit can be modeled by a combination of any number of water rights input records. The various types of water rights discussed here can be combined in a variety of ways to represent a particular actual “system water right.”

### Water Right Types

Each water right input record includes specification of the type of water right as either type 1, 2, 3, or 4. The types of system operations which can be included with each type of water right are summarized in Table 2 and described below.

Table 2  
**Types of WRAP3 Water Rights**

Allowable Operations	Type of Water Right			
	1	2	3	4
diversions from streamflow depletions	yes	yes	no	yes
refill one reservoir from streamflow depletions	yes	no	no	no
releases from multiple reservoirs	yes	yes	yes	yes
hydroelectric power generation	yes	no	no	no
diversion requirements specified as a function of reservoir storage and naturalized streamflows	no	no	no	yes

In a typical river basin, most actual water rights will likely be represented as type 1 rights. A type 1 right allows a diversion to be met from streamflow depletions and/or storage in one or more reservoirs. One reservoir can be refilled from streamflow depletions or releases from other reservoirs in the system. The one reservoir which can be refilled and the diversion 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 in the basin. A type 1 right can include either a diversion requirement or a hydroelectric energy generation requirement, but not both. Of course, two type 1 rights can be used in combination to model both hydropower and a diversion. Both the diversion and energy requirements can be zero, in which case the right would simply refill storage in the one reservoir. Releases or withdrawals can be made from a maximum of 50 reservoirs. A run-of-river diversion right can be represented as a type 1 (or type 2) right with no reservoirs. A run-of-river hydropower right can be represented as a type 1 right with one reservoir with inactive but no active storage capacity. Although the water right types are not pertinent to WRAP2, the WRAP2 procedure is equivalent to a type 1 right with one or no reservoir and no hydropower.

A type 2 right provides a mechanism for modeling a situation in which releases or withdrawals from one or more reservoirs supplement streamflows in meeting a diversion target without replenishing storage in any of the reservoirs. A type 2 right is identical to a type 1 right except that no reservoir is refilled. A type 2 right could be mimicked by a type 1 right with an extra reservoir with zero storage capacity.

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 streamflow entering the river below the dams. Unlike a type 3 right, a type 1 or 2 right makes reservoir releases only after the streamflow at the diversion location is depleted.

A type 4 right allows a permitted diversion to be specified as a function of reservoir system storage and naturalized streamflow at the diversion location. Thus, buffer zone operations can be simulated in which certain water demands are curtailed whenever reservoir storage falls below specified levels. Input data includes a table of diversion amount versus total storage in specified system reservoirs, as well as the annual water right diversion target with associated monthly water use distribution factors incorporated in the other water right types. For a given month, the permitted diversion target is computed as the minimum of: (1) the value determined by linear interpolation of the diversion versus storage table and (2) the value determined from the permitted annual diversion and monthly use factors. An optional feature is also included in the model which limits releases from reservoirs to a user-specified percentage of the naturalized streamflow at the diversion location.

### Multiple Reservoir Release Rules

All water rights are limited to one permitted diversion or energy generation target amount. A type 1 water right can also include maintenance of storage in one “primary” reservoir. (Of course, any number of reservoirs can each have one or more separate rights to maintain their individual storages.) Releases or withdrawals can be made from one or more “secondary” reservoirs to meet the diversion or hydropower target and refill storage in the one primary reservoir associated with a right. WRAP3 is dimensioned to allow a water right to include a maximum of 50 reservoirs.

In a multiple reservoir system, a set of rules is required for the model to determine amounts to be released from each of the alternative reservoirs. For example, Figure 1 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 streamflow 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.

## Figure 1. Multiple Reservoir System

An important aspect of the multiple reservoir system release rules involves the impact on water availability of the other more senior rights in the river basin. For example, the senior right at control point CP-6 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, WRAP3 includes optional capabilities for simulating pump/pipeline 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 the input data, 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.

As illustrated by Figure 2, a reservoir includes an active pool and inactive pool. The inactive pool is dead storage from which releases or withdrawals cannot be made. The inactive pool can be drawn down only by evaporation. Releases and withdrawals to meet water rights requirements are made from the active pool. For purposes of developing multiple-reservoir operating rules, the active pool is divided into two zones. 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. 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. Reservoir storage balancing is based on computing a ranking factor for each reservoir in the system as follows.

The release is made from the reservoir with the greatest value for the rank factor. If the release results in the reservoir storage dropping from zone 1 into zone 2 while storages in the other reservoirs are still 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 “weighing factor” for each reservoir used in the above formula is specified by the user in the input data. If the values of the weighing factor are the same for all the reservoirs, the operating rule simply balances the percent depletion of either zone 1 or zone 2 of each reservoir. 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. The weighing factors allow some reservoirs to be emptied faster than others. Thus, the user defines the operating rules by inputted values for zone 1 and zone 2 cumulative storage capacities and the weighing factor for each reservoir in the system.

## Figure 2. WRAP3 Reservoir Pools and Zones

A type 4 water right provides additional flexibility for specifying operating rules for either a multiple reservoir system or a single reservoir. With a type 4 right, the permitted diversion amount is inputted as a function of the total storage in the one or more reservoirs included in the system. The reservoir releases can also be limited to not-to-exceed a percentage of the naturalized streamflow at the diversion control point. Thus, diversions can be partially or completely curtailed as available reservoir storage is depleted or reservoir releases limited to a specified percentage of the streamflow which would have existed without basin development.

### Flood Control Operations

The various types of water rights can be combined in any number of ways to represent actual water rights permits and system operating strategies. The model was designed to provide flexibility for analyzing a comprehensive range of operations for water supply, hydropower, instream flow maintenance, and other conservation purposes. Although no special features are included specifically for flood control, reservoir flood control operations can be included in an approximate manner in modeling multiple purpose operations.

Flood control operations are based on emptying designated flood control pools as rapidly as possible without contributing to streamflows at downstream control points exceeding target allowable nondamaging levels. A type 4 water right can be used to specify an instream flow requirement (diversion with 100% return flow) as a function of system storage. For flood control operations, the instream flow requirement would be specified as an allowable nondamaging channel capacity, if storage is in the flood control pool, and zero otherwise. A type 1 right, with a permitted diversion of zero, would be used to fill the flood control storage capacity of each reservoir. For a multiple reservoir system, the flood control pool of each reservoir would be designated as zone 1 to define release rules based on balancing storage depletions. Zone designation would not be necessary for a single flood control reservoir.



## CHAPTER 4 COMPUTATIONS PERFORMED BY WRAP2 AND WRAP3

### Basic Concepts

The WRAP (WRAP2 or WRAP3) computations proceed by month (period) and, within each month, by water right on a priority basis with the right having the smallest priority number being considered first. The water right diversion amount is diverted as long as streamflow, not yet appropriated by senior water rights, or reservoir storage is still available. A shortage occurs if sufficient streamflow and/or storage are not available to supply the water right that month. The reservoir storage capacity associated with the water right is filled to the extent allowed by available streamflow.

The naturalized streamflow provided in the WRAP input data for each control point represents the streamflow which would occur at that location assuming no water users, reservoirs, or other activities of man in the river basin. WRAP computes streamflow depletions associated with each water right and unappropriated streamflows associated with each control point. An accounting is maintained of the effect of each streamflow depletion on streamflow availability at all other control point locations.

A streamflow depletion represents the streamflow taken by a water right in a given month to (1) meet the target water right diversion and (2) fill the reservoir storage capacity. Water rights diversions are supplied by streamflow depletions, as long as streamflow is available, and then by reservoir storage depletions, if reservoir storage is available. WRAP3 also provides the option for diversions to be met by releases from reservoir storage but not streamflow. Evaporation also depletes reservoir storage. A streamflow depletion in a given month will often include refilling of reservoir storage capacity depleted during previous months.

Unappropriated streamflow represents water still available after all streamflow depletions or the water that flows past the basin outlet into the ocean or other receiving body. The unappropriated streamflow is the portion of the inputted naturalized streamflow not used by the water rights included in the simulation. The computed unappropriated streamflows, as well as inputted naturalized streamflows, are treated as cumulative or total flows rather than incremental or local flows.

End-of-period reservoir storage content is computed in the model based on the water balance equation:

$$S_2 = S_1 + D - R - E$$

where  $S_2$  and  $S_1$  denote the storage at the end of the current and previous months, respectively, and  $D$ ,  $R$ , and  $E$  denote streamflow depletions, releases or withdrawals, and evaporation during the month. The streamflow depletion ( $D$ ) represents reservoir inflows minus spills and minus releases to meet downstream senior water rights. In the model, streamflow depletions are computed as the portion of streamflow used to refill reservoir storage and meet diversion requirements. Spills are not actually computed. The releases or withdrawals ( $R$ ) are to meet diversion requirements of water rights associated with the reservoir. Evaporation ( $E$ ) is computed by multiplying the computed average water surface area during the month by an inputted net evaporation rate. The water surface area is determined from an inputted storage versus area relationship. Since the average area is dependent on both  $S_2$  and  $S_1$ , an iterative solution of the water balance equation is required.

For a given month, the computations are performed for each water right in priority order. As the water rights are considered in turn, an accounting is maintained of the amount of streamflow still available at each control point location. Available streamflow at each control point is treated as total flows rather than incremental or local flows. As a first step in the computations for a water right, the amount of streamflow available to the right is determined as the minimum of the available streamflows at each of the downstream control points, including the control point of the water right. After the streamflow depletion, return flow, and other variable values are determined for a water right, the amounts of water still available at that control point and all downstream control points are decreased to reflect the streamflow depletion. The water available at the control point location at which the diversion return flow is returned as well as all downstream control points is increased to reflect the return flow. The next water right, in priority order, is then considered.

A fundamental concept of the model is that, with the exceptions noted below, each water right is impacted only by more senior water rights. During each period (month), as each right is considered in turn in priority order, the various quantities (such as diversions, diversion shortages, streamflow depletions, storages, etc.) are computed as if the other more junior rights did not exist. Thus, the most senior right in the river basin meets its permitted diversion target and refills its reservoir storage capacity as if no other water users or storage facilities existed in the basin. As explained below, exceptions to this basic concept are related to (1) return flows and (2) multiple water rights with storage capacity in the same reservoir.

Diversion return flows reenter at a user-specified control point during either the same month as the diversion or during the next month. With the user-specified option of the return flow returning during the same month as the diversion, senior water rights are not affected by return flows from junior water right diversions. However, with the next month option, junior right return flows, associated with diversions from either streamflow and/or storage, can increase the water available to senior rights.

Any number of water rights can include storage capacity in the same reservoir. In the computations for a senior water right, the beginning-of-period storage can be impacted by the computations for the previous period for junior rights at the same reservoir. Multiple rights in the same reservoir are modeled as follows. A reservoir storage capacity is included with the input data for the right. The storage capacity associated with a water right is the total or cumulative capacity to which the reservoir can be filled by the computations for that right. Unless a WRAP3 type 4 right is specified, storage depletions to meet diversions can be made by any of the rights associated with the reservoir until the active pool is completely empty. The end-of-period storage depends upon all the rights associated with the 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-to-exceed the storage capacity associated with the right. Because of this, 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.

### **Organization of the Simulation**

The computations and input/output data handling performed by WRAP2 and WRAP3 are outlined in Table 3 from a general overview perspective. After first reading a major portion of the input

data, the simulation is performed in a set of three 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. Certain output data records are written to the WRAP output file at the completion of each of the two inner loops. The output records are described in Table 5, which is discussed in more detail in the later section on WRAP input and output.

At the beginning of a WRAP execution, a subroutine reads all the input data except streamflows and evaporation rates. Various manipulations of the input data are performed including a ranking mechanism for identifying the priority order of the water rights.

The annual loop begins with reading the streamflow and evaporation data for each of the 12 months of that year. The computations are then performed on a monthly basis. The data on the control point and reservoir/hydropower output records, as listed in Table 5, represent summations for all rights associated with the control point or reservoir. Thus, these records are outputted each month at the completion of the water rights loop.

Most of the system simulation computations are performed within the water rights loop. For a given month, the computations are repeated for each water right in priority order. For a given water right, the computations begin with a determination of the streamflow available to the right. Streamflow availability is determined as the lesser of the streamflow amounts still available at the control point of the water right and at each of the downstream control points. Water balance computations are then performed to compute the streamflow depletion, reservoir evaporation, end-of-period storage, return flow, and diversion shortage for the water right. The interrelationships between the variables necessitate an iterative algorithm. For WRAP3 multiple reservoir system operations, the releases and storages for all the system reservoirs are computed. Upon completion of the water right computations, the streamflow amounts still available at the control point of the water right and at all downstream control points are decreased by the streamflow depletion. The streamflow amounts still available at the control point of the return flow and all downstream control points are increased by the return flow amount.

### **WRAP3 System Computations**

The basic concepts and organization of the simulation described above are identical for both WRAP2 and WRAP3. However, WRAP3 contains optional capabilities, not included in WRAP2, related primarily to simulation of a comprehensive range of operating strategies for multiple-purpose, multiple-reservoir systems. WRAP3 also has optional capabilities for handling negative incrementals in the streamflow input data. Another WRAP3 option provides flexibility in specifying reservoir storage levels at the beginning of the simulation. These features require additional input data and computations beyond the requirements for the basic WRAP2 simulation. The optional WRAP3 features, not included in WRAP2, are addressed in the following paragraphs.

Table 3  
**Outline of WRAP Simulation**

\*\*\* Input Data

- read all input records except streamflows and evaporation rates
- rank water rights in priority order
- perform various other input data manipulations
- write first five records of output file

\*\*\* Annual Loop

- read streamflow and evaporation data for year

\*\*\* Monthly (Period) Loop

\*\*\* Water Right Loop

- check streamflow availability
- perform water balance computations
- adjust available streamflows
- write water rights output records

\*\*\*

- write control point output records
- write reservoir/hydropower output records

\*\*\*\*\*

\*\*\*\*\*

### Water Right Types

As previously discussed, WRAP3 includes options for specifying a right to be one of four distinct types, 1, 2, 3, or 4, which are defined in Tables 1 and 2. The computations within the water rights loop proceed differently according to water right type. The differences are primarily in determining the permitted diversion amount for a right and in specifying how the permitted diversion is to be met. In all cases, the available streamflow is calculated as described in the previous section. The target streamflow depletion is then computed according to the type of right.

For type 1 rights, the target streamflow depletion is the permitted diversion amount plus the volume needed to refill storage in the primary reservoir, if one exists, accounting for evaporation and previous depletions made available to the primary reservoir by senior rights associated with that reservoir. A right is only allowed to refill storage in its primary reservoir, and only up to the storage capacity of the right. A streamflow depletion is then made to meet the target depletion. If the available streamflow is greater than the target depletion, the target depletion is removed from the available streamflow and the computations continue on to the next right in priority order. If there is not enough available streamflow to meet the target depletion, the additional amount (variable MAKEUP) is released from system reservoirs, according to the multiple reservoir release rules described previously.

The basic water right is a type 1. Computations for a type 1 right in WRAP3 are essentially identical to WRAP2. However, in WRAP2, a water right may be associated with only one reservoir. The additional amount needed to meet the target depletion cannot be released from other reservoirs. A WRAP3 simulation with all type 1 rights and no secondary reservoirs for any right is identical to a WRAP2 simulation. In both models, the permitted diversion amount is given priority over refilling of reservoir storage when insufficient water is available to meet the permitted diversion amount and refill storage. The computations to replenish storage in the primary reservoir also assume that the total capacity of the reservoir is that of the current right being examined. 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.

Computations for a type 2 right are identical to a type 1 right except that 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 is not allowed a primary reservoir, it is allowed to have secondary reservoirs from which to receive releases.

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

Diversion requirements for type 4 rights are calculated as a function of several variables. After the available streamflow is determined, the permitted diversion is determined as the minimum of a fixed (storage-independent) target and the value determined from linear interpolation of the storage-diversion table input for the right. The fixed target is the inputted permitted annual diversion multiplied by a set of monthly distribution factors, as for the other water right types. If no limit on reservoir releases is desired, the required amount is met from streamflow depletion and reservoir releases, and the diversion shortage is calculated similar to a type 2 right. Reservoir releases, however, may be limited by an optional user input percentage of the naturalized monthly streamflow at the water right's control point.

### Multiple Reservoir Releases

Beginning Versus End-of-Period Storage. For water rights allowed to receive releases from multiple secondary reservoirs, two options are available on which to base release decisions. As stated earlier, the secondary reservoirs eligible to release from a storage zone for a water right are ranked from high to low according to a priority number consisting of the product of a user input zone factor and the percent full of that respective reservoir zone. WRAP3 allows the user to specify whether to use the beginning-of-period storage or the intermediate end-of-period storage in computing the priority number. Using the beginning-of-period storage option will allow the user to track easily how the reservoir release decisions are made in a month. Using the end-of-period storage option more closely resembles real-time reservoir release decisions, but doesn't allow the user to track how the reservoir release decisions were made during a particular month because the storage levels used for a release are changed

by the releases themselves and by junior water rights associated with the reservoir.

Release Constraints. Reservoirs upstream of a diversion location are assumed to make direct releases to meet a water right diversion requirement. Reservoirs located in basins other than that of the water right diversion are treated as if a conveyance structure exists to transport water directly to the diversion location. However, reservoirs that are physically able to release only to control points that are downstream of the diversion location are limited to streamflow depletions made by senior rights downstream of the diversion location. These reservoirs are referred to as “downstream” reservoirs. The amount of water that a downstream reservoir may release is limited to the amount of water that has been passed through the diversion location to meet senior water right depletions. The effect of this constraint is best described by example.

Referring to Figure 1, the three upstream reservoirs RES-A, RES-B, and RES-C are able to release directly to the system diversion location. Downstream reservoir RES-D is not. Assume naturalized inflows to control points CP-4 and CP-6 are 20 ac-ft and 30 ac-ft, respectively. The senior right diversion requirement at CP-6 is 17 ac-ft, while the system diversion requirement at CP-4 is 25 ac-ft.

The senior right reduces the available streamflow to the system diversion to 13 ac-ft, resulting in 14 ac-ft to be released from system reservoirs. Of the 20 ac-ft of inflow to CP-4, seven 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 seven 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 14 ac-ft if sufficient storage exists.

The downstream release constraint is determined on a control point basis. If a second system diversion exists at control point CP-4 that is junior to the first, the amount that RES-D may release for the second system diversion is constrained by the amount that RES-D released for the first. If RES-D released four ac-ft for the first system diversion, then it is limited to releasing three ac-ft for the second because a total of seven ac-ft were passed through the control point to the senior water right. WRAP3 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. If negative incremental inflows occur within a basin, specifying negative incremental options 1 or 2 may cause erroneous release decisions to be made due to the mechanism used in the accounting of flows.

WRAP3 includes an option that will remove the downstream reservoir releases constraint and treat a downstream reservoir as if a conveyance facility exists between the reservoir and the diversion locations.

### Hydroelectric Power Computations

Hydroelectric energy computations are based on the following equations:

$$\begin{aligned} \text{energy} &= (\text{power}) (\text{time}) \\ \text{power} &= \gamma Q H_e (\text{unit conversion factor}) \end{aligned}$$

where:

$\gamma$  = unit weight of water  
 $Q$  = discharge through turbines during month  
 $H$  = head = mean reservoir water surface elevation for month minus tailwater elevation  
 $e$  = plant efficiency  
 $t$  = time interval (one month)

In the model, these equations are expressed as:

$$\text{energy} = QHe(\text{POWFCT})$$

where:  $\text{POWFCT} = \gamma t$  (unit conversion factor).

As discussed in a later section on units, the user can either input a value for POWFCT or use the default provided in the model.

If a water right is a hydropower right, a permitted firm energy is input instead of a permitted diversion amount. A reservoir storage versus elevation table and constant tailwater elevation are input in order to compute head. When a non-hydropower water right's 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 user's input specifications. The hydropower permitted diversion is computed as the additional release amount needed to meet the permitted firm energy target, considering all releases for more senior rights which 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, a different assumption is made as to the refilling of storage in the reservoir. In order to compute the energy produced correctly, the convention of ignoring storage capacity above the water right's capacity in a multiple-right reservoir is relaxed somewhat. A right will make streamflow depletions and receive releases from secondary reservoirs to meet the permitted firm energy as well as refill storage up to its permitted storage capacity. If the storage in the reservoir is above the capacity of the right, the right will make depletions and releases necessary to just maintain the storage level while meeting the permitted firm energy. The target depletion is computed as the additional water that must be passed through the reservoir turbines assuming that the end-of-period storage is either the water right's storage capacity or the current storage level, whichever is higher, plus the amount needed to refill storage. The storage used in the assumptions is the current end-of-period storage for that reservoir. Junior rights associated with that reservoir may increase or decrease that storage amount, changing the energy actually produced at the reservoir. The value output for the energy produced on a reservoir/hydropower record in a WRAP3 '.OUT' file represents the energy produced by the most junior hydropower right of the reservoir. The intermediate values of energy for senior rights is listed in the WRAP3 '.SYS' file.

The appropriate streamflow depletions and reservoir releases are then made. If the target depletion is less than the sum of the available streamflow and/or the secondary reservoir releases, the firm energy requirement is met without drawdown of the reservoir. If the target depletion is greater than that sum, the actual energy produced must be computed in an iterative manner because storage will be released from the reservoir to meet the firm energy requirement.

A run-of-the-river hydropower right, with no reservoir storage, may be modeled with zero storage in a “dummy” reservoir. The appropriate storage elevation curve entered would then be a constant elevation. A run-of-the-river hydropower right with inactive reservoir storage is modeled with the total storage capacity equal to the inactive capacity.

### Optional Beginning-Period-Storage

The default assumption concerning reservoir storage at the beginning of the first period of the simulation is that all reservoirs begin the simulation full. It is possible, however, to specify a lower beginning-period-storage at any reservoir in the basin. This may be necessary to add conservatism to an analysis of water right reliabilities, to more closely model an actual circumstance, or because computer storage limitations necessitate dividing the simulation into two or more runs.

The output from the model is voluminous. It may be desired to simulate a portion of a long period-of-record on one run, and the rest of the period-of-record on ensuing runs. The beginning-period-storages at the reservoirs will simply be the ending storages from the preceding run. If the next month option is specified for return flow from any water right, it would also be necessary to add the return flow from the last period of the preceding run to the inflows of the first period of the current run.

### Counting of Basin Components

WRAP2 requires the user to input the total number of water rights, control points, and uses. For the convenience of the user, WRAP3 does not. WRAP3 does the counting internally as part of its computations. Both programs will count the number of reservoirs included in the system.

### **Negative Incremental Inflow Options**

Naturalized streamflows at each control point for each month of the simulation are provided as input data. The incremental inflow between control points is defined as the naturalized streamflow at the downstream control point minus the corresponding flow at the upstream control point(s). For example, in Figure 1, the incremental inflow between control points CP-2, CP-3, and CP-4, for a given month, is the flow at CP-4 minus the sum of the flows at the upstream CP-2 and CP-3. Since streamflow usually increases in a downstream direction, incremental inflows are typically positive. However, flows at an upstream location exceeding corresponding flows at a downstream location is not unusual. Negative incremental inflows may result from channel seepage losses between control point locations, large travel times causing the effects of precipitation events to reach adjacent control points in different time periods, and/or gaging or data input errors.

Total, rather than incremental, naturalized streamflows are provided as WRAP input. The computational algorithms are also based on total flows. As previously discussed, within the water rights loop for a given month, the amount of streamflow available to a water right is computed as the lesser of the yet unappropriated (considering all higher seniority rights) streamflows at the control point of the right and all downstream control points. For example, in Figure 1, the streamflow available to a water right at control point CP-2 is the lesser of the still unappropriated total streamflows at CP-2, CP-4, or CP-6. Thus, negative incremental inflows between CP-2 and either CP-4 or CP-6 reduce the streamflow



available to water rights at CP-2. The term “negative incremental” refers to the naturalized streamflow at the downstream CP-6 and/or CP-4 being less than that at CP-2. The impact of negative incremental inflows in the computations may or may not properly represent the actual situation being modeled. Thus, WRAP3 provides optional capabilities for dealing with negative incremental inflows in the naturalized streamflow data.

This WRAP3 feature involves determining the negative incremental inflows at the beginning of the simulation computations. The negative incrementals can be used by the model to adjust the naturalized streamflows prior to the water rights simulation and/or can be written to a file for information purposes. The negative incremental inflows can be computed from the perspective of either “looking downstream” or “looking upstream.”

Computations of negative incremental inflows looking downstream are identical to the computations of available streamflow within the water rights loop. The algorithm simply compares the naturalized streamflow at each control point downstream of the current control point to the naturalized streamflow at the current control point. The negative incremental inflow is the highest difference between the naturalized streamflow at the current control point and any control point physically downstream. The value of negative incremental inflow is either zero or a negative number indicating the amount that must be subtracted from the current control point to equate its naturalized streamflow to the lowest naturalized streamflow occurring below the current control point.

Computations looking upstream sum total incremental inflow at all control points above the current control point. Computations move from control point to control point, adjusting the incremental inflows in an iterative manner until no more incremental inflows are added. The resulting value at each control point is either zero or positive indicating the amount that must be added to the inflow at that control point to remove the negative incremental inflow.

WRAP3 includes four negative incremental inflow options. These options involve adjusting the naturalized streamflows prior to the system simulation and/or writing negative incremental inflow data to a file for information. The user selects one of the options listed below and also specifies whether or not a negative incremental output file is to be created. With options 1 and 2, negative incremental inflows are identified for informational purposes only with no adjustments to the WRAP simulation. Options 3 and 4 involve adjustments to the naturalized streamflows used in the simulation computations. Negative incremental inflows are computed identically the same with options 2, 3, and 4, but the computed values are used differently.

Option 1. - The default option 1 involves no adjustments to the naturalized streamflow input data. Negative incrementals are computed looking downstream for information purposes only. The user can request an output file containing zero or negative numbers representing the reduction in naturalized streamflows required at each control point for each time period to eliminate negative inflows between the control point and downstream control points. A WRAP3 option 1 simulation is the same as a WRAP2 simulation, except WRAP2 does not provide an output file alerting the user to the negative incremental inflows.

Option 2. - Option 2 also involves no adjustments to the naturalized streamflows. Thus, the simulation results are identical for WRAP3 options 1 and 2 and WRAP2. However, with option 2, negative incremental inflows are computed, for information only, looking upstream. The negative

incremental inflow output file is written as zeros and positive numbers representing the increase in naturalized streamflows required at a control point to remove negative incremental inflows between it and upstream control points.

Option 3. Option 3 involves computing the negative incrementals looking upstream, just as option 2, and then adjusting the naturalized streamflows accordingly at each control point. The simulation is based on forcing all negative incremental inflows to zero.

Option 4. - Option 4 also involves computing incremental inflows looking upstream but only makes the “extra” naturalized flows available at the control points at which they occur.

Example. - For the river basin of Figure 1, for a given month, naturalized streamflows of 18, 20, 9, 15, 4, and 12 acre-feet occur at control points CP-1, CP-2, CP-3, CP-4, CP-5, and CP-6, respectively. Since the streamflows at certain downstream locations are less than corresponding flows at upstream locations, a situation involving negative incremental inflows exists.

Options 1 and 2 involve no adjustments to the naturalized streamflows. At the beginning of the WRAP simulation, a streamflow amount of 12 acre-feet is available to a water right at CP-2, for that particular month. Note that the naturalized streamflow at CP-6 is controlling water availability at CP-2. For option 1, the incremental inflow output file would include values of -3 ac-ft for CP-4; -8 ac-ft for CP-2; and zero for the other control points, for that month. An option 2, 3, or 4 incremental file would contain values of 14 ac-ft for CP-4; 17 ac-ft for CP-6; and zero for the other control points.

Options 3 and 4 involve adjustments to the naturalized streamflows. The flows at CP-4 and CP-6 are increased to 29 ac-ft and 33 ac-ft, respectively. For either option 3 or 4, at the beginning of the simulation, a streamflow amount of 20 ac-ft is available to a water right at CP-2. With option 3, the simulation begins with streamflow amounts of 29 and 33 ac-ft available for water rights at CP-4 and CP-6, respectively. With option 4, the simulation begins with streamflow amounts of 15 and 12 ac-ft available to water rights located at CP-4 and CP-6.

Comparison. - With options 1 and 2, the naturalized streamflow availability to water rights at a control point is reduced by negative incremental inflows occurring between that control point and either upstream or downstream control points. Thus, water availability is conservatively low in the simulation. For option 3, all negative incremental inflows are forced to zero and water availability is not reduced at all, resulting in conservatively high water availability. For option 4, streamflow availability at a control point is reduced by negative incremental inflows occurring upstream but is not affected by negative incremental inflows occurring downstream. Option 4 will be the most realistic assumption in many actual river basin modeling situations.

### **Watershed Flow Option**

Water right diversions and storage typically occur at many remote ungaged locations throughout the watersheds above the control points. The October 1996 version of WRAP2 and WRAP3 includes a watershed flow option to supplement 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. The watershed flow option is used for rights at locations other than their assigned control points. The WRAP model

limits water available to these rights to the lesser of naturalized streamflows at the site or yet unappropriated flows at their assigned control point and downstream control points. The naturalized streamflows at the watershed sites are determined as a function of the flows provided as input for a specified control point or alternatively as a function of incremental flows between specified control points. The watershed flow option provides flexibility for determining the naturalized streamflows at the water right location in different ways ranging from simply using a drainage area ratio to more complex functional relationships requiring input of several parameters.

The algorithm for determining naturalized flows at the location of a water right based on naturalized flows at one or more control points is based on the following equations.

$$F_{WR} = aS^b + cB + C$$

$$S = F_{CP} - B$$

$$B = L \quad \text{if } F_{CP} > L$$

$$B = F_{CP} \text{ and } S = 0 \quad \text{if } F_{CP} < L$$

$$F_{CP} = \text{FLOW1} - \text{FLOW2} - \text{FLOW3}$$

where:

- $F_{WR}$  = computed flow at water right location [FLAMT]
- $S^{WR}$  = computed storm runoff [STORM]
- $B$  = computed base flow [BASE]
- $L$  = input limit between base flow and storm runoff [FL(IWS,5)]
- $C$  = input constant flow [FL(IWS,4)]
- $a$  = input coefficient [FL(IWS,1)]
- $b$  = input exponent [FL(IWS,2)]
- $c$  = input coefficient [FL(IWS,3)]
- $F_{CP}$  = naturalized streamflow input for control point [CPFLOW]
- $\text{FLOW1}$  = flow at downstream control point [FLCP(IWS,1)]
- $\text{FLOW2}$  = flow at upstream control point [FLCP(IWS,2)]
- $\text{FLOW3}$  = flow at upstream control point [FLCP(IWS,3)]

The parameters (L,C,a,b,c) and control point identifiers [FLCP(IWS,1), FLCP(IWS,1), FLCP(IWS,1)] are input on FL records. The names of the variables in the FORTRAN code are shown above in brackets. The identifier IWS input in field 11 of the water right (WR) record links the water right to a FL record with these input data. A negative integer value for IWS on the WR record indicates that a FL record with the identifier positive IWS will be provided. If field 11 of the WR record is blank or zero, the watershed flow option is not used for that water right.

A typical application of the watershed flow option consists of simply applying the ratio of the drainage areas of the water right location and the control point. The drainage area ratio is provided on the WR record, and a FL record is not needed. A positive real value for IWS in field 11 of a WR record indicates that the watershed flow option is used without providing a FL record. The parameter “a” is IWS, b is one, and c, C, and L are zero, resulting in:

$$F_{WR} = aF_{CP}$$

where  $F_{WR}$  is the naturalized streamflow at the water right site and  $F_{CP}$  is the naturalized flow at the control point assigned to the water right in field 3 of the WR record.

The watershed flow option computational algorithm provides a general framework for relating naturalized streamflows at water rights locations, which may be scattered throughout a watershed, to naturalized streamflows at control points provided as input to the model. Methodologies can be developed to estimate the parameters a, b, and c based on ratios of watershed areas, stream lengths, mean precipitation, and watershed parameters such as the curve numbers (CN) that are widely used in Soil Conservation Service watershed modeling methods. Other diversions and return flows may be reflected in the parameter C. The base flow parameter L can be determined from analysis of gaged streamflows at representative locations.

## **CHAPTER 5 COMBINED USE WITH OTHER MODELS**

### **Streamflow Naturalization and Synthesis**

The streamflow data provided as WRAP input will typically be historical flows adjusted to remove significant human-induced effects related to reservoir construction, water use diversions, and other activities. The WRAP naturalized streamflow input data represent flows which would have occurred if man had not developed the river basin or if the water management facilities and activities reflected in the water rights data did not exist.

Homogeneous streamflow input data, representing basin conditions at a specified past, present, or future point in time, are a fundamental requirement for any type of river basin or reservoir system simulation study. Although numerous generalized reservoir system simulation models are available and widely used, development of naturalized streamflow data for input to the models is typically performed on an ad hoc study-by-study basis. Generalized computer programs and data compilation procedures for adjusting historical streamflows to remove nonhomogeneities are not widely available.

Complete series of homogeneous streamflow data covering the entire period-of-analysis at all pertinent locations are required. Missing data in the streamflow records at one location are filled in by a regression analysis with available streamflow data at pertinent nearby gage locations. Computer programs, are readily available for reconstituting missing monthly data in streamflow records based on regression analysis. Such programs include “*HEC-4 Monthly Streamflow Simulation*,” developed by the USACE Hydrologic Engineering Center, and “*MOSS-IV Monthly Streamflow Simulation*,” which is an expanded version of HEC-4 available from the Texas Water Development Board. These models also include capabilities for synthesizing sequences of synthetic streamflows of any desired length based on preserving certain statistical characteristics of the naturalized historical data.

The Texas Water Commission (TWC) and Texas Department of Water Resources (TDWR) developed water availability models for several major river basins during the 1970’s and 1980’s in support of the water rights adjudication process. The Texas Natural Resource Conservation Commission (TNRCC) is updating these models using the Water Rights Analysis Package (WRAP). Development of naturalized streamflows was a major component of the water availability models developed by the TWC and TDWR during the 1970-1980’s. A period-of-analysis was adopted for these models beginning in 1940 and ending sometime between 1972 and 1981. Initial efforts in developing updated water availability models using WRAP are incorporating these naturalized streamflows from the previous TWC and TDWR models. The Interactive Water Rights Retrieval (IWR) System is a TNRCC database for managing the data from the water availability models, which includes naturalized streamflows as well as other information.

### **HEC-3 and HEC-5**

Several generalized computer models were used in the previously cited Brazos River Basin study (Wurbs *et al.* 1988) along with TAMUWRAP, including HEC-4 and MOSS-IV cited above and the following reservoir system simulation models available from the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers.

## HEC-3 Reservoir System Simulation for Conservation HEC-5 Simulation of Flood Control and Conservation Systems

HEC-3 is somewhat similar to WRAP3. Whereas diversion requirements are met in a user-specified priority order in WRAP3, diversion requirements are met in an upstream to downstream order in HEC-3. HEC-5 has similar capabilities as HEC-3 for simulating conservation operations and much more comprehensive capabilities for simulating flood control operations. Unlike WRAP, HEC-3 and HEC-5 have no capabilities for simulating a priority water rights permit system. However, HEC-3 and HEC-5 provide capabilities not available in WRAP, particularly in regard to hydroelectric power and flood control operations. HEC-3 and HEC-5 contain options for computing firm yields in a single run of the model. Multiple simulation runs are required to iteratively compute firm yield with WRAP.

The simulation capabilities of HEC-3/HEC-5 and WRAP can be combined. Streamflow depletions and unappropriated streamflows computed with WRAP can be provided as streamflow input data for HEC-3 or HEC-5. The WRAP adjusted streamflow represents the streamflow available to specified water rights after all other water rights have been considered. Thus, HEC-3 or HEC-5 can be run with streamflow data representing only the streamflow available institutionally as well as hydrologically to the pertinent reservoir system or water management entity.

TABLES includes options for converting streamflow depletions and unappropriated flows from a WRAP output file into input records which can be conveniently incorporated into either a HEC-3 or HEC-5 input data file. The TABLES options also allow inclusion of evaporation rate records along with the streamflow records prepared for a HEC-3 or HEC-5 input data file.

## CHAPTER 6 WRAP INPUT AND OUTPUT DATA OVERVIEW

A WRAP (WRAP2 or WRAP3) input file contains a series of required and optional records representing the stream/reservoir/rights system being modeled. The input records also include several job control parameters that invoke various model options, such as selection of data to output. Both WRAP2 and WRAP3 will run the same basic data set with identical results. However, WRAP3 contains optional capabilities, not included in WRAP2, which require additional input data. Input data requirements are outlined below. Detailed instructions for developing the input file records are provided in Appendix A. An example is presented in Appendix C.

Both models write identical main output and error files. WRAP3 writes two additional optional output files which will be described as well. The post-processor program TABLES reads the WRAP main output file and develops data tabulations and summaries.

### Units

The units for all the input data must be consistent, but any units can be used. Streamflow, diversion, and evaporation data must have consistent volume per month units which correspond to the reservoir storage volume and area units. Typical units are acre-feet for the reservoir storage and volume/month or volume/year quantities; acres for reservoir surface area; and feet for monthly evaporation rates. The naturalized streamflow and evaporation rate input data provided on IN and EV records are multiplied by factors inputted in the fourth and fifth fields of the CP records for each control point. For example, if permitted diversions and reservoir storage input data are in acre-feet and reservoir areas are in acres but mean monthly naturalized streamflows and monthly evaporation rates are inputted in second-feet-day (ft<sup>3</sup>/s·day) and inches, respectively, the conversion factors 1.9835 ac-ft/sfd and 0.083333 ft/inch would be entered as the multipliers in the control point (CP) records.

Several of the tables created by program TABLES include the label “acre-feet” in the headings. Thus, the headings of these particular tables will be incorrect if acre-feet is not used as the basic volume unit. Otherwise, any units can be used if kept consistent.

The variable POWFCT, entered in the fifth field of the JD record of a WRAP3 input file, is a multiplier factor used in the hydroelectric power computations, which reflects unit conversions as well as the computational time period and unit weight of water. The energy computations are based on the following equation:

$$E = \gamma QHt(\text{unit conversion factor}) = QHe (\text{POWFCT})$$

where: POWFCT =  $\gamma t(\text{unit conversion factor})$ . POWFCT has a value of 0.0010237 if the following quantities are used:

$$\begin{aligned} \text{unit weight } (\gamma) &= 62.4 \text{ lb/ft}^3 \\ \text{time period } (t) &= 1 \text{ month} \end{aligned}$$

and the other variables in the above equation are expressed in the following units: energy (E) in megawatt-hours, discharge (Q) in acre-feet/month, and head (H) in feet. Efficiency (e) is dimension-

less. The model uses a default of POWFCT = 0.0010237 if no value is entered in the fifth field of the JD record. This value is computed below for illustrative purposes. POWFCT values for other units can be determined by adjusting the values shown below accordingly.

$$\begin{aligned}\text{unit conversion factor} &= (43,560 \text{ ft}^3/\text{ac}\cdot\text{ft})(3.766 \times 10^{-10} \text{ megawatt}\cdot\text{hr}/\text{ft}\cdot\text{lb}) \\ &= 0.000016405\end{aligned}$$

$$\begin{aligned}\text{POWFCT} &= \gamma t (\text{unit conversion factor}) \\ &= (62.4 \text{ lb}/\text{ft}^3)(1 \text{ month})(0.000016405) \\ &= 0.0010237 \text{ megawatt}\cdot\text{hour} \cdot \text{month} / (\text{ac}\cdot\text{ft} \cdot \text{ft})\end{aligned}$$

### **Input Data Records and Requirements**

Each input data record begins with a two-character identifier. The records are listed by identifier in Table 4. The record types are pertinent to both WRAP2 and WRAP3, except for the OR, WI, PV, and PE records which are used only for WRAP3. Input data requirements for each type of record are discussed below.

Table 4  
**WRAP2 and WRAP3 Input Records**

**T1,T2,T3** - titles or headings  
**\*\*** - comments  
**JG** - water rights groups for output  
**JR** - reservoirs for output  
**JD** - job control  
**UC** - monthly use factors  
**CP** - control point information  
**WR** - water right  
**WS** - water right storage  
**OR** - multiple-reservoir operating rules (WRAP3 only)  
**WI** - storage/diversion table for type 4 right (WRAP3 only)  
**SV** - storage/area table volumes  
**SA** - storage/area table areas  
**PV** - storage/elevation table volumes (WRAP3 only)  
**PE** - storage/elevation table elevations (WRAP3 only)  
**ED** - end of data for basin description  
**IN** - naturalized streamflows  
**EV** - net reservoir evaporation rates

#### **Title Records (T1,T2,T3)**

Three title records are required at the beginning of the input file. The titles, headings, and/or comments provided on the title records are reproduced at the top of each output file created by the



models. The title records may be blank if desired.

### Job Control Record (JD)

The JD record must follow the three title records. It contains the number of years in the simulation, the number of periods (months) per year and the year at which to start the simulation. WRAP2 requires that the user count the number of water rights, control points, and use types contained in the simulation and enter this information on the JD record. WRAP3 does not require the user to enter this information, but rather automatically makes the counts as it reads the input file. Information regarding several WRAP3 features are input on this record, including hydropower unit conversions, negative incremental inflow options, and system reservoir release decision options. The JD record also includes switches for output options.

### Water Right Group Output Record (JG)

Many river basins will contain several hundred or thousand water rights. Computed results can be aggregated by control point and written to the output file as control points records. Control point output records represent a summation or aggregation of data for all water rights associated with the control point. The JD record includes a parameter to specify that output records be written for either all or none of the control points.

Output for each individual water right will typically not be needed for all of the rights included in a simulation. The JG record allows the user to specify the water rights for which information is written to the main output file as individual water rights records. The user may list the identifiers of up to 60 water rights on a series of JG records. At least one JG record must be entered. The list of identifiers follows an integer number in the first field of the first JG record. If it is desired to output simulation results for every water right in the system, a negative number may be entered on the JG record. If it is desired to output no information for individual water rights, a zero may be entered.

It is also possible to follow a short hand method for listing water rights for output. The identifiers in a JG record may signify water right groups. A water right is defined as part of a group if its water right identifier, control point identifier or its optional group identifier match any of the identifiers listed on a JG record. A water right's group identifier may be entered in the last field of the WR record for that right, described below. With this option, it is possible to output results for (1) an individual water right by listing its identifier on a JG record, (2) all of the water rights located at a control point by listing that control point's identifier on a JG record, and (3) all water rights that have group identifiers on the WR record matching identifiers on a JG record.

The post-processor program TABLES allows summary tables of simulation results for water rights groups to be built as well as summary tables for individual water rights. To enable TABLES to do this, the output records containing water right results must be labeled with the water right group identifiers instead of the water right identifiers. Inputting a positive number into the next to last field of the JD record will cause the group identifiers of all water rights to be output instead of the water right identifiers.

### Reservoir Output Record (JR)

Output associated with each individual reservoir will often not be needed for all the reservoirs included in a simulation. Up to 60 reservoirs may be listed for output on a series of JR records. If it is desired to flag all of the reservoirs for output, a negative number may be entered in the first field of the JR record. If it is desired to output no simulation results for individual reservoirs, a zero may be entered in the first field.

The JG records must be entered before the JR records in WRAP2. WRAP3 allows either the JR or the JG records to be listed first. Both models require at least one JR and at least one JG record. If more than one of either record is listed, the entire set of that record must be entered consecutively. The JR and JG records must follow the JD record in the input file.

### Monthly Use Factors Record (UC)

Each water right (WR) record includes an annual permitted diversion and a use type identifier. Selection of monthly distribution factors, provided on UC records, is the only utilization in the simulation computations of the use type identifier. UC records are required for each type of water use. The permitted annual diversion amount (or hydroelectric energy) is divided into monthly diversion requirements according to monthly use factors entered on a series of required UC records following the JG and JR records. These records include the six-character alpha-numeric use type identifier and associated set of monthly use factors. These use factors do not have to sum to unity. Both WRAP2 and WRAP3 sum the use factors and then divide each use factor by that sum to transform the use factors into decimal fractions summing to unity. Both models are currently dimensioned for 12 uses. The types of water use could be associated with particular uses, such as irrigation, municipal, industrial, and hydropower, or otherwise represent different distributions of use over the year.

### Control Point Record (CP)

The control point (CP) records follow the UC records. One CP record is required for each control point. This record contains the six-character alpha-numeric identifier of the control point, the identifier of the control point immediately downstream, and two conversion factors by which to multiply the monthly evaporation rate (EV records) and naturalized streamflow (IN) data input for the control point. If either conversion factor is entered as zero or blank, the factor is defaulted to unity. Both programs are currently dimensioned for 50 control points. If a control point has no control points downstream, the identifier entered for the next downstream control point is 'OUT'.

### Water Right Record (WR)

Data describing water rights are entered on a series of WR and WS records. WR records contain the six-character water right, control point, and use identifiers, identifier of the control point at which return flows reenter the stream system, priority number of the water right, annual permitted diversion, and return flow factor. WRAP3 also requires that the water right type (1,2,3 or 4 or hydro-power) be entered. Several of these data have default values and various options associated with them.

If return flows reenter at the control point directly downstream, the return flow control point identifier field may be left blank. The return flow control point may also be listed as the control point location of the water right itself if desired. If the water right returns flow out of the basin, then the return flow location identifier should be listed as 'OUT', or a zero return flow factor should be entered.

The return flow factor is the decimal fraction of the diversion met for a water right that is returned to the river system. The return flow factor may be entered as a number greater than unity if desired. This will allow a water right to “import water” into the basin by returning a higher amount than it diverted. A user option allows the return flows to reenter the stream system during either the same month or the next month after the diversion. The next month option is activated by entering a negative sign before the return flow factor.

If a hydroelectric power right is specified, the annual energy requirement is input in the place of the permitted annual diversion. Energy requirements for multiple hydropower rights must be entered as cumulative in order of priority. A hydropower right must have an energy requirement that is equal or higher than any senior hydropower right associated with a reservoir. WRAP2 contains no hydropower capabilities.

It is possible for several rights to have the same priority number. If the priority number is the same for two or more rights, priority is assigned in the order that the water rights are entered in the input file.

#### Water Right Reservoir Storage Record (WS) - WRAP2

If a water right includes storage capacity at a reservoir, a WS record must follow the WR record. A WRAP2 right is allowed to refill storage and make withdrawals from only one reservoir. The required data on the WS record includes the reservoir identifier and the permitted storage capacity of the right. The storage capacity is the total cumulative active storage level to which the reservoir can be filled under the water right. Several water rights may be associated with a single reservoir, each with a different storage capacity. The storage capacities must be cumulative according to the priority of the water rights. A junior right is required to have a storage capacity at a reservoir equal to or greater than the storage capacity of any other more senior rights associated with that reservoir.

The control point of the first right to be associated with a reservoir is assumed to be the location of the reservoir. Care should be taken to ensure that all other rights associated with the reservoir be located at that control point as well. The storage-area data is provided with the first water right at a reservoir and not repeated for subsequent rights at the same reservoir. Coefficients for the storage-area function are entered in the WS record. A negative entry for the first coefficient indicates that a storage-area table will follow on SV and SA records.

#### Water Right Storage Record (WS) - WRAP3

In WRAP3, a water right can be associated with up to 50 reservoirs with WS records for each reservoir following the WR record. One reservoir, called the primary reservoir, is analogous to a WRAP2 reservoir. Only the one primary reservoir is allowed to refill storage. The water right diversion and primary reservoir must be located at the same control point. Type 1 and hydropower rights are the only water right types allowed to refill storage. A type 1 right or hydropower right may have either zero or one primary reservoir and up to 50 secondary reservoirs. The primary reservoir must be cited on the WS record immediately following the WR record. All reservoirs on the second and subsequent WR 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 4 rights are classified as secondary reservoirs.

The WRAP3 WS record includes fields for the inactive storage capacity, storage content at the beginning of the simulation, tailwater elevation for hydropower computations, and hydropower plant efficiency. For non-hydropower rights, designation of lakeside diversions on the WS record allows hydroelectric power turbines, associated with a more junior hydropower right, to be bypassed. By default, all diversions and releases from a reservoir are assumed to contribute to power generation for junior hydropower rights at the reservoir, unless otherwise specified. Hydroelectric power can be generated only at a primary reservoir. If the field for beginning-of-simulation storage content is left blank, the reservoir is assumed to start the simulation full to its maximum capacity.

### Multiple-Reservoir Operating Rules Record (OR) - WRAP3

If two or more reservoirs are associated with a water right, an OR record must follow each WR record to define the multiple-reservoir operating rules. An OR record can also be provided for a single secondary reservoir associated with a water right, if needed to either specify the control point location or to flag pipeline conveyance. The OR record includes the reservoir control point, storage capacity at top of zone 2 (bottom of zone 1), zones 1 and 2 release priority factors, and the gravity flow versus pipeline switch. The control point identifier is not required if already provided by a previous WR or OR record. The reservoir zones and weighing factors are defined in the discussion of multiple reservoir release rules on pages 16-20.

If the last field of the OR record is blank or zero, 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. If the OR record has a negative integer in the last field, this constraint is removed. 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.

### Storage-Diversion Table for a Type 4 Right (WI) - WRAP3 only

Immediately after a WR record defining a type 4 right, a set of up to 12 pairs of data representing the required diversion amount as a function of storage is entered. Note in Appendix A that data is not entered in the same format as storage-area or storage-elevation data. The storage volumes represent the total volume contained in all of the reservoirs associated with the right. The diversion amounts represent the permitted diversion amount of the right at any given storage level. Permitted diversion values are obtained from linear interpolation of the table.

### Storage-Area Records (SV,SA)

For each reservoir flagged by a negative number in the first storage-area coefficient field of the WR record, a set of two SV and two SA records is required at the end of the water right data. The records may contain up to 12 pairs of data that define the storage volume versus surface area relationship for the reservoir. The SV and SA records represent volume and area, respectively. The data is entered from low to high with both SV records entered before the SA records. The corresponding reservoir identifier must be entered on the first SV record. The programs are dimensioned to allow up to 50 storage-area tables to be input. The sets of SV and SA records are grouped together at the end of all the WR and WS records.

The storage volume versus water surface area relationship for a reservoir with inactive storage may be defined differently in WRAP2 and WRAP3. WRAP3 allows explicit designation of an inactive pool, but WRAP2 does not. For WRAP2, an active storage versus area relationship is entered as input data. For a reservoir with inactive storage, a positive nonzero area will be associated with zero active storage. For WRAP3, if a nonzero inactive (bottom of active pool) storage is entered, a total storage (inactive plus active) versus area relationship is required. The WRAP3 and WRAP2 storage/area relationships are identical if the value of inactive storage (bottom of active pool) is entered as zero in WRAP3. This discussion is equally pertinent for storage-area relationships expressed as coefficients on a WS record or as a table on SV and SA records.

WRAP3 allows the reservoir level to be drawn down below the bottom of the active pool (top of inactive pool) by evaporation. WRAP2 does not. However, if a positive area is associated with zero storage, WRAP2 allows evaporation to deplete streamflow even if the active storage capacity is empty.

#### Hydropower Storage-Elevation Records (PV,PE) - WRAP3 only

Each reservoir associated with a hydropower right requires a set of two PV and two PE records at the end of the water rights data. The records may contain up to 12 pairs of data that define the storage versus water surface elevation relationship for the reservoir. The PV records represent the storage volume, the PE records represent the corresponding water surface elevation. The elevation data should not be adjusted to account for tailwater elevation. A constant tailwater elevation is entered on the WS record for the water right. The data should be entered from low to high with both PV records entered before the PE records. The corresponding reservoir identifier must be entered on the first PV record. The data are entered identically to storage-area records and may be entered anywhere after the water rights data records and before the end of data record.

#### Watershed Flow Records (FL)

Naturalized streamflows at a water right site can be computed as a function of the naturalized flows input at one, two, or three control points by use of field 11 of the water right (WR) record in combination with a FL record. A FL record is provided only for each negative integer value of IWS provided in field 11 of the WR records. A blank or zero WR record field 11 indicates that the water right location is at the control point or the watershed flow option is not used. If a positive number for IWS is entered, the flows at the water right site are computed by multiplying the control point flows by IWS. The positive value for IWS would typically be a drainage area ratio. A negative integer value of IWS links the water right to a FL record. A positive value of the identifier IWS is entered in the second field of the FL record. All parameters required to compute naturalized flows for the water right as a function of control point flows are provided on the FL record. Dimension limits are set at 200 FL records. All FL records are grouped together, in any order, just before the end-of-data (ED) record.

#### End-of-Data Record (ED)

After the necessary data describing the stream/reservoir/rights system components have been entered, an end-of-data record is entered prior to entering the inflow and evaporation data.

#### Streamflow or Inflow Record (IN)

Naturalized streamflow data for each control point are entered for each month of each year of the simulation on a series of IN records. Each control point will have two IN records for each year inflows, with the first record containing the control point identifier, year, and the first six months of naturalized streamflows. If the inflow is identical for two or more control points, a negative year may be entered on the second IN record with the identifier of the control point for which flows have been entered previously. The inflows at the control point will be set equal to the inflows of the previously entered control point. If unit conversions are required, the inflow data entered for each control point will be multiplied by the inflow multiplication factor listed on the CP record for each control point. The IN record repetition and CP record multiplier features also allow naturalized streamflows at a control point to be computed by multiplying the streamflow input data at that or another control point by a factor such as a drainage area ratio. All inflow records for a year are entered consecutively. Control points within each annual block of IN records may be entered in any order.

### Reservoir Evaporation Rate Record (EV)

Evaporation data for each control point with a reservoir is entered similarly to inflows. Each year's evaporation records must be entered after the inflow records. The evaporation data represents the net monthly evaporation rate specified as a depth. The evaporation rates for each control point will be multiplied by the evaporation rate multiplication factor listed on the CP record for the control point. Unit conversions may be provided with these factors. Control points within each annual block of EV records can be entered in any order.

### Comment Record (\*\*)

Comment records delineated by a double asterisk may be entered anywhere within the input data after the first three title records (T1,T2,T3) and before the end of data record (ED). The comments or notes are for information only and are not read or used in any way by the model.

## **Output Data Description**

WRAP2 produces a simulation output file and an error message file. WRAP3 creates these same two output files plus two additional optional files. The WRAP output files include:

- error message file (WRAP2 and WRAP3)
- main simulation output file (WRAP2 and WRAP3)
- system release/hydropower file (WRAP3)
- inflow adjustment file (WRAP3)

Program TABLES reads the main WRAP simulation output file and system release/hydropower file and develops data tabulations and summaries. Some additional simple computations, such as computing reliability statistics, are performed by TABLES in conjunction with organizing and presenting the WRAP simulation results. Program TABLES is discussed in detail in a later section. TABLES does not use the other two files in any way. They are written for informational purposes only and may be read or printed out by the user.

### Error File (WRAP2 and WRAP3)

The data input routine contains several data checks that take place as the data is read from the input file. Fatal errors, such as missing required records, cause the program to terminate. If a fatal input data error is encountered, an appropriate message is written to the screen and an identical message is written to the error file before program termination. Several non-fatal errors which may occur during program execution have been defined as well. Non-fatal errors will cause an appropriate message to be written to the error file, but the program will not terminate. A common non-fatal error might be a reservoir evaporation computation not iterating to sufficient precision. The data causing the error will customarily be written to the error file for the user to check.

### Output File (WRAP2 and WRAP3)

The WRAP2 and WRAP3 output file is outlined in Table 5. The file contains the simulation results for each control point and for whichever water rights and reservoirs have been flagged for output. As indicated in Table 3, the data are written, as the computations proceed, on a month-by-month basis, with water right data written in order of priority. The format of this file is designed to compactly store the voluminous output data in the order in which it is computed. Although the file can be viewed directly by the model user, the format is not convenient for interpreting simulation results. Program TABLES provides the capability to reorganize, tabulate, and summarize the simulation results in a variety of formats.

The output file begins with four title lines; the first line identifies the file as a WRAP2 or WRAP3 file, and the remaining three lines are the title records from the input file. The fifth line of the output file contains, from left to right, the year on which the simulation started, the number of years of the simulation, the number of periods per year, the number of control points in the basin, the number of water rights output and the number of reservoirs output. The simulation results are then written in a columnar format in blocks of data representing each month of the simulation. Within each month of simulation results, output records for the chosen water rights are written first, followed by the control point output records, followed by the output records for the chosen reservoirs. The content of the individual records is described below. Any differences between WRAP2 and WRAP3 are identified where appropriate.

Water right output records. Each water right output record contains, from left to right, the water right or group identifier, the diversion shortage that occurred, the monthly permitted diversion amount, the evaporation volume that occurred if the right is associated with a reservoir, the end-of-period storage of the reservoir, the streamflow depletion the water right made during the month, the streamflow available to the right before the streamflow depletion, all water that was released from secondary reservoirs to meet the diversion and/or refill storage, and the year and month of the simulation.

The difference between the permitted diversion and the diversion shortage represents the diversion amount actually met from streamflow depletions and reservoir releases. Both are written as zero or positive. The values of permitted diversion and diversion shortage for a hydropower right are written as zero.

The evaporation and end-of-period storage represent the values that would occur assuming no other junior rights are associated with the reservoir. The reservoir evaporation will be written as a negative number if a negative net evaporation rate occurred at the control point. The values written for

the most junior right at the reservoir are therefore the actual values that occur for the reservoir. Any values written for senior rights at the reservoir are intermediate values only.

The streamflow depletion represents the streamflow that the water right appropriated to meet the permitted diversion amount and/or refill storage and meet evaporation. In months with a negative net evaporation rate, the streamflow depletion may be written as a negative number. In this case, the water right actually makes water available to the basin by catching precipitation that falls onto the reservoir surface.

In WRAP3, the value for reservoir releases includes only releases from secondary reservoirs to meet the storage and permitted diversion requirements of the right. The amount that is released from the primary reservoir is not included. The value of releases from system reservoirs is always zero in WRAP2 output files.

Control point output records. Control point records provide a summation of output data for all the water rights at each control point and are similar in format to water right output records. Each record contains, from left to right, the control point identifier, the sum of the shortages and permitted diversions for all water rights, evaporation and end-of-period storage for all reservoirs, and streamflow depletions for all rights located at the control point. The final three fields contain the unappropriated flow remaining at the control point after all streamflow depletions have been made, the sum of the return flow returned at the control point from the current and previous month, and the naturalized streamflow at the control point.

Table 5  
**WRAP2 or WRAP3 Output File**

First Five Records of WRAP Output File

WRAP3 (MARCH 1993 VERSION) OUTPUT FILE  
TITLE1  
TITLE2  
TITLE3  
YRST NYRS NPRDS NCPTS NWROUT NREOUT

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)

Definition of Variables on Fifth Record

YRST - first year of simulation  
NYRS - number of years in simulation  
NPRDS - number of periods in a year (12 assuming a monthly interval)  
NCPTS - number of control points in WRAP output file  
NWROUT - number of water rights in WRAP output file  
NREOUT - number of reservoirs in WRAP output file

Total Number of Records in WRAP Output File



number of records = 5 + (NYRS\*NPRDS) \* (NWROUT + NCPTS + NREOUT)

### Water Rights Output Records

Each record provides data for a water right for a given period (month). The records for all of the water rights are grouped together for a given period. The 80 character record contains 10 variables stored in the format indicated below. Releases from other reservoirs (item 8 below) can be nonzero only for a WRAP3 multiple-reservoir water right. This field is always zero in a WRAP2 output file.

FORMAT (A6, 5F9.1, F10.1, F9.1, 2X, 2I4)

1.	water right identifier	(A6)
2.	diversion shortage	(F9.1)
3.	permitted target diversion	(F9.1)
4.	evaporation	(F9.1)
5.	end-of-period storage	(F9.1)
6.	streamflow depletion	(F9.1)
7.	available streamflow	(F10.1)
8.	releases from other reservoirs	(F9.1)
9.	year	(I4)
10.	month	(I4)

Table 5 Continued  
**WRAP2 or WRAP3 Output File**

### Control Point Output Records

Each record provides data for a control point for a given period (month). The records for all the control points are grouped together for a given period. The 80 character record contains nine variables stored in the format indicated below. A control point record contains data summed for all the water rights located at the control point or data, such as naturalized and unappropriated streamflows, not associated with a particular water right. Return flows are cited at the control point at which the flows reenter the stream.

FORMAT (A6, 5F9.1, F10.1, F9.1, F10.1)

1.	control point identifier	(A6)
2.	diversion shortage	(F9.1)
3.	permitted diversion	(F9.1)
4.	evaporation	(F9.1)
5.	end-of-period storage	(F9.1)
6.	streamflow depletion	(F9.1)
7.	unappropriated streamflow	(F10.1)
8.	return flow	(F9.1)
9.	naturalized streamflow	(F10.1)

### Reservoir/Hydropower Output Records

Each record provides data for a reservoir and/or hydroelectric power plant for a given period (month). All the reservoir/hydropower records are grouped together for a given period. The 80 character record contains nine variables stored in the format indicated below. The variables related to hydroelectric power generation are always zero in a WRAP2 output file. WRAP3 may output records for reservoirs with or without hydroelectric power.

FORMAT (A6, 2F10.1, 6F9.1)

1.	reservoir identifier	(A6)
2.	hydroelectric power shortage (+) or secondary energy (-)	(F10.1)
3.	energy generated	(F10.1)
4.	reservoir evaporation	(F9.1)
5.	end-of-period storage	(F9.1)
6.	inflows to reservoir from streamflow depletions	(F9.1)
7.	inflows to reservoir from releases from other reservoirs	(F9.1)
8.	releases from reservoir accessible to hydroelectric power turbines	(F9.1)
9.	releases from reservoir not accessible to hydroelectric power turbines	(F9.1)

Reservoir/hydropower output records. Reservoir output records include, from left to right, the reservoir identifier, power shortage at the reservoir, energy produced at the reservoir, evaporation, end-of-period storage, streamflow depletions made available to the reservoir, releases from other reservoirs made available, releases from the reservoir through the outlet works and lakeside releases from the reservoir.

The hydroelectric energy produced at the reservoir in each month is calculated from the average water surface elevation of the reservoir, the total flow through the outlet works for all rights associated with the reservoir, and the tailwater elevation input for the most junior hydropower right associated with the reservoir. The power produced is computed assuming that the turbine capacity is unlimited. Hydropower shortages are calculated as the algebraic difference between firm power and the power produced at the reservoir. Positive shortage values signify that insufficient water was released from the reservoir through the outlet works to produce the firm power 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 water right diversion and storage requirements, assuming unlimited turbine capacity. The hydropower values are output as zero in a WRAP2 simulation.

Streamflow depletions made available to a reservoir include depletions for diversions as well as depletions to refill storage and meet evaporation. Depletions for diversions are assumed to enter a primary reservoir and then are released either lakeside or through the reservoir’s outlet works.

Releases made by a reservoir include both releases as a primary reservoir and releases as a secondary system reservoir. The releases written to a reservoir output record include both primary and secondary releases. WRAP2, allowing only primary releases and containing no hydropower capabilities, makes no distinction between lakeside or outlet work releases. WRAP2 releases are written as outlet work releases by convention.

### System Release/Hydropower File (WRAP3)

The system release file written by WRAP3 lists the releases from the primary and secondary reservoirs for each month of the simulation for each water right chosen for output. The file also writes the firm energy and the energy produced by each water right. The release from a primary reservoir is

simply the diversion met by the right. This amount may include water from streamflow depletions and water released from secondary reservoirs as well as water taken from storage in the primary reservoir.

The data for each right is written as a single record in the following order:

- water right or water right group identifier,
- number of reservoirs associated with the right,
- year and month,
- energy target and energy generated,
- and reservoir identifiers and associated releases listed in the same order as the WS records in the input file.

The energy target and energy generated are written as zero for non-hydropower rights. This is the only information available regarding the energy generated by senior rights when several rights generate energy at the same reservoir. The system release/hydropower file is read by program TABLES to develop tables of system reservoir releases for a water right or water right group.

### Inflow Adjustment File (WRAP3)

If specified on the job control (JD) record, the information obtained by the different options for computing negative incremental inflows is written for each control point for each month of the simulation. Data is written for each control point a year at a time. Depending upon the option chosen, the data written for each control point is either negative, zero or positive, indicating the amount that must be added to or subtracted from the inflows to remove the negative incremental inflow.

## **CHAPTER 7**

### **PROGRAM TABLES**

The computer program TABLES reads the WRAP (WRAP2 or WRAP3) input and output files, performs various data manipulations, and develops output tables and data listings. The WRAP output data, as well as input data, is quite voluminous. The WRAP2/WRAP3 output file is designed to store large quantities of data in a concise format. TABLES provides convenient and flexible capabilities for data organization, tabulation, and presentation.

#### **Files**

An execution of TABLES begins with an interactive routine in which the user provides file names for all pertinent files, which may include:

- TABLES input file
- TABLES output file
- WRAP (WRAP2 or WRAP3) input file
- WRAP (WRAP2 or WRAP3) output file
- WRAP3 system release/hydropower file

The TABLES input file specifies the tables and data listings to be developed. The tables and data listings are stored in the TABLES output file. The data from which the tables and data listings are compiled are read from WRAP input and/or output files. The TABLES input and output files are always named and opened. One or more WRAP input or output files are required depending on the types of tables or data listings specified in the TABLES input file.

#### **Program Organization**

TABLES consists of a main program and several subroutines. The main program opens the required files, checks the identifier on each record of the TABLES input file in turn, and calls the appropriate subroutines. The WRAP input and output files are read and the specified tables and data listing are developed and written to the TABLES output file by the subroutines. Each subroutine is associated with a specific type of table or data listing.

A majority of the TABLES input records activate subroutines which simply rearrange and tabulate, with appropriate table headings, selected data read from the WRAP input or output file. However, some of the subroutines also include simple computational algorithms. In some cases, summing or other arithmetic combining of data are involved. Other subroutines include a little more complex arithmetic operations. For example, a 1SRT record calls a subroutine containing a water rights sorting algorithm. A 2REL record involves computing period and volume reliabilities. A 2PER record activates a subroutine which converts reservoir storages from volume units to percentages of storage capacity and also develops a storage/duration table.

#### **TABLES Input File**

The tables or data listings to be developed are specified in a TABLES input file. Each type of table or data listing is associated with the selected four-character record identifier. Each record in the

TABLES input file begins with a four-character record identifier, followed by parameters providing instructions associated with that particular type of table or data listing. All records are optional; there are no required records. No limits are placed on the number or order of the records, with the exception of TITL records which are limited to a maximum of five records and must be located at the beginning of the input file. Any number of each type of record, except the TITL records, can be placed in any order in the input file. TABLES reads one record of the input file; develops the tables and data listings specified by the input record; stores the tables and data listings in the TABLES output file; and then goes on to the next record of the input file. TABLES input records are listed in Table 6 and discussed below. Detailed instructions for developing a TABLES input file are provided in Appendix B. The example problem in Appendix C illustrates the format and headings for several types of output tables.

### Miscellaneous Records

TITL records provide titles or headings to be reproduced on the cover page and at the top of each job type 2 or 3 table. Zero to five TITL records may be used.

COMM records provide a means to insert comments or notes at any location in the input file. COMM records are not read or used in any way by the program.

The ENDF record denotes the end of the input file. Any records following the ENDF record will not be read. Although an ENDF record is not required, a message is printed on the terminal screen, as a reminder, if the input file has no ENDF record.

### Job Type 1 Records

1REC, 1SUM, and 1SRT records specify listings and tabulations of data which are read from a WRAP input file. Inclusion of a 1REC record in a TABLES input file results in a listing of specified WRAP input records. The 2-character identifiers of the WRAP input records to be included (or alternatively to be omitted) in the listing are entered on the 1REC record.

A 1SUM record results in a summary table of water rights data by control point, type of use, water right type, or water right group. This table includes number of rights, diversion amounts, number of reservoirs, storage capacity, and range of priorities.

A 1SRT record requests a listing of water rights sorted in priority order or a listing sorted by type of use, control point, water right type, or water right group in priority order.

### Job Type 2 Records

Job type 2 records result in tables being developed from the data contained in the water right, control point, and reservoir/hydropower records of a WRAP output file, as listed in Table 5. A WRAP output water right record contains data for an individual water right. A control point record contains data summed for all the water rights located at the control point or data, such as naturalized or unappropriated flows, not associated with a particular water right. A reservoir/hydropower record contains data for a reservoir including hydroelectric energy generation data if a power plant is located at the reservoir.

Table 6  
**Program TABLES Input Records**

Miscellaneous Records

TITL - titles or headings  
COMM - comments  
ENDF - end of input data file

Job Type 1 Records - Tabulations from WRAP2 or WRAP3 Input File

1REC - listing of specified input records  
1SUM - water rights summary by control point or type of use  
1SRT - listing of water rights sorted by priority, type of use, control point, or water right type

Job Type 2 Records - Tabulations from WRAP2 or WRAP3 Output File

2SCP - summary table for a control point  
2SWR - summary table for a water right  
2SRE - summary table for a reservoir  
2SGP - summary table for a water right group  
2SUM - summary table of summation of selected water rights  
2SBA - summary table for river basin (all control points)  
2REL - reliability and shortage summary  
2NAT - naturalized streamflows  
2UNA - unappropriated streamflows  
2DEP - streamflow depletions  
2SHT - shortages  
2STO - reservoir storages  
2PER - percentage storage of selected reservoirs and storage-duration for selected reservoirs

Job Type 3 Records - Develop IN and EV Records in HEC-3 or HEC-5 Format

3NAT - IN records of naturalized streamflows with or without EV records  
3UNA - IN records of unappropriated streamflows with or without EV records  
3DEP - IN records of streamflow depletions with or without EV records  
3HEC - IN records of naturalized streamflows, unappropriated streamflows, streamflow depletions, or the summation of streamflow depletions plus unappropriated flows, for selected control points and selected water rights, with or without EV records

Job Type 4 Records - Tabulations from System Release/Hydropower File

4SWR - system reservoir releases for selected water rights  
4SGP - system reservoir releases for selected water rights groups

2SGP, 2SCP, 2SWR, and 2SRE records result in summary tables for specified water right groups, control points, water rights, or reservoirs, respectively. These tables consist of either a monthly or annual tabulation of all the data items contained on the WRAP control point, water right, or reservoir/hydropower records.

A 2SUM record results in a summation of the data on the WRAP water rights output records of specified water rights. The 2SUM output table, for the summation of data for several selected water rights, has the same headings and format as the 2SWR table for a single water right. If group identifiers are output instead of water right identifiers, a 2SUM output table is identical to a 2SGP table.

A 2SBA record results in a basin summary table, with the same headings and data as the 2SCP record cited above, with the tabulated data (except naturalized and unappropriated streamflows) being the summation of the data for all the control points. The naturalized and unappropriated streamflows in the 2SBA table are the maximum of the values found at the control points.

2REL record calls for a table containing period and volume reliabilities and a shortage summary for either selected water rights, water right groups, control points, or hydroelectric power reservoirs. Three separate 2REL records would be used to obtain three separate reliability and shortage tables for selected water rights, control points, and hydroelectric power reservoirs, respectively. Period reliability is the number of months for which shortages occurred divided by the total number of months in the simulation. Volume reliability is the total volume of shortages (or total energy shortage) divided by the corresponding total permitted diversion volume (or permitted firm energy). The shortage summary is expressed in terms of the number of months and the number of years during the simulation during which the water right diversion shortage, or hydroelectric energy shortage, equalled or exceeded specified percentages of the permitted diversion or hydroelectric energy target.

2NAT, 2UNA, 2DEP, 2SHT, and 2STO records are associated with tables of naturalized streamflows, unappropriated streamflows, streamflow depletions, shortages, and end-of-period reservoir storages, respectively. The tables include one line for each year of the simulation, with each line containing the year, 12 monthly (January through December) values of the variable, and the total for the year.

The 2PER record tabulates end-of-period reservoir storage as a percentage of a user-specified storage capacity. This table is particularly useful for reviewing simulation results for multiple-reservoir system operations. The WRAP3 multiple-reservoir system release rules are based on balancing percent depletions of specified storage zones. A storage-duration table is also developed in terms of the percentage of months for which the storage content equalled or exceeded specified percentages of storage capacity. Sets of 2PER records are used to specify the reservoirs to be included in the tabulation and, for each reservoir, the storage capacities ( $C_1$  and  $C_2$ ) at the top and bottom, respectively, of the conservation pool or zone. The end-of-period storages ( $S$ ) are read from the reservoir/hydropower record of the WRAP output file. The storage percentages in the 2PER table are computed as follows:  
percent storage =  $((S - C_1) / (C_2 - C_1)) * 100\%$

### Job Type 3 Records

3HEC, 3NAT, 3UNA, and 3DEP records convert naturalized streamflows, unappropriated streamflows, streamflow depletions, and unappropriated flows plus streamflow depletions, from a WRAP

output file, and evaporation rates, from a WRAP input file, to IN and EV records for inclusion in a HEC-3 or HEC-5 (USACE, Hydrologic Engineering Center 1981 & 1982) input data file. Job type 3 records also facilitate combining WRAP with a salt concentration simulation model presently being developed at TAMU, which also uses the HEC-3 type input data format.

HEC-3 has a single fixed format for the IN and EV records. HEC-5 allows several optional formats for the individual IN or EV records, including the option of using the “HEC-3” format. However, the arrangement or order of the IN and EV records, for multiple years and control points, are different between HEC-3 and HEC-5. TABLES creates each individual IN or EV record in the “HEC-3” format, which can be used in either HEC-3 or HEC-5. Each record contains the record identifier (IN or EV), control point or reservoir identifier, year, and 12 monthly streamflow or evaporation rate values for the specified year and location. The Fortran format is (A2,I4,I2,12F6.0). TABLES options allow the IN and EV records, for multiple years and locations, to be arranged in either HEC-3 or HEC-5 order. With HEC-3 format, the IN records for all control points are grouped by year. The EV records for all reservoirs for a given year follow the set of IN records for that year. With HEC-5 format, all the IN records for all years are grouped together for a given control point followed by a set of IN records for all years for the next control point, and so forth. The EV records are grouped together at the end of the set of all IN records. Options are provided on each of the job type 3 records for either including or omitting the evaporation rate (EV) records. Inputted multiplier factors can be used for converting units for the streamflow and evaporation rate data. The inflow (IN) records created by TABLES may contain either of the following:

- summation of streamflow depletions for specified water rights plus unappropriated flows at the corresponding selected control points (3HEC record)
- unappropriated flows at selected control points (3HEC record)
- summation of streamflow depletions for specified water rights (3HEC record)
- naturalized streamflows for selected control points (3HEC record)
- naturalized streamflows for all control points (3NAT record)
- unappropriated flows for all control points (3UNA record)
- summation of streamflow depletions for all water rights at all control points (3DEP record)

A 3NAT record creates IN records containing the naturalized streamflows read from the WRAP output file for all control points. Options specify either HEC-3 or HEC-5 format and either include or omit the EV records. The control point identifier placed on the IN records is assigned as integers starting with one (1,2,3, ...) in the order in which the control points records are arranged in the WRAP output file. The reservoir identifiers placed on the EV records are likewise assigned as integers starting with one (1,2,3,...) in the order in which the EV records are arranged in the WRAP input file. 3UNA and 3DEP records are identical to the 3NAT record except unappropriated flows (3UNA record) or the total streamflow depletions at each control point (3DEP record) are written on the IN records instead of naturalized streamflows (3NAT). Only one TABLES input record is required to create IN and EV records for all the control points.

A set of 3HEC records can be used to develop any output file which can be created with either a 3NAT, 3UNA, or 3DEP record as well as providing other features not available with these records. 3HEC records provide greater flexibility, but a separate record is required for each control point. A set of 3HEC records consists of an initial 3HEC record providing general specifications, followed by a specific 3HEC for each control point for which output is desired. 3HEC records provide the only



mechanism, within TABLES, for adding the unappropriated flows to the streamflow depletions at a control point. 3HEC records also allow the user to specify each of the individual control point or reservoir identifiers to be written on the outputted IN and EV records. With 3HEC records, the user selects the control points and/or water rights for which streamflow data is output as IN records and the evaporation rate data to include in the associated EV records.

The EV records are read from a WRAP input file. The set of EV records for each year must be in the same order by control point. TABLES numbers (1,2,3,...) the EV records by control point in the order found in the WRAP input file, for purposes of identifying the EV records associated with each 3HEC record. The user specifies the appropriate EV control point identifier or counter (EVCT) on the 3HEC record for the control point. With a 3NAT, 3UNA, or 3DEP record the “n” sets of EV records are assigned, in order, to the first “n” control points for which IN records are provided. If there are IN records for more control points than EV records, the last control points will not be assigned EV records. Thus, 3HEC records (rather than a 3NAT, 3UNA, or 3DEP record) are required if a simple one-to-one correspondence does not exist between EV control points and IN control points entered in the same order in the WRAP input file.

WRAP input data can include a “negative year” to indicate that IN or EV records for one control point are being repeated for another. TABLES reads all streamflow data, including naturalized streamflows, from a WRAP output file. Thus, all WRAP manipulations of streamflow data, including control point repetition of naturalized streamflows, are properly reflected in the TABLES output. However, TABLES does not allow automatic repetition, for multiple control point locations, of EV records read from a WRAP input file. The user must assign EV records to control points on the 3HEC records. Unless the variable “NEGYR” on the 3HEC record is flagged, the TABLES output file will include a message written each time a “negative year” is read on a WRAP EV input record.

#### Job Type 4 Records

Job type 4 records result in tables being developed from the data contained in a system release/hydropower file. 4SWR or 4SGP records provide monthly or annual tabulations of system releases from all reservoirs associated with a water right or water right group. Each table can include up to 15 reservoirs. Releases tabulated for a primary reservoir include streamflow depletions made to meet the permitted diversion as well as water released or withdrawn from storage.

## CHAPTER 8 RUNNING THE MODEL

WRAP2, WRAP3, and TABLES are compiled and executed as separate individual programs. Both fortran source codes and compiled executable versions of the programs are available. The user can develop WRAP (WRAP2 or WRAP3) and TABLES input files following the instructions provided by Appendices A and B using any editor. The executable programs are run by typing the appropriate name, either WRAP2, WRAP3, or TABLES, assuming a microcomputer is being used with the Microsoft disk operating system (MS DOS) or equivalent. Execution of either of the programs begins with an interactive session which defines the pertinent input and output files.

The computer files involved in executing the programs are listed in Table 7. The terms "ROOT" and "EXT" refer to the root and extension of a file name (ROOT.EXT), which is named by the user. Some filenames have a root specified by the user, but the extension portion of the filename is specified by the program, such as OUT, ERR, ADJ, and SYS. The user-defined "ROOT" can also include a drive and directory path. Table 7 also indicates the unit numbers assigned to the files in the fortran open and format statements, which is useful information only when examining the fortran source codes.

The WRAP3 multiple-reservoir system release computations and hydroelectric power computations involve use of the temporary scratch files SCR10 and SCR11 to store intermediate results. The scratch files are automatically created; used to write, store, and retrieve computed data; and erased by the program. The user has the option of assigning a drive and directory path for the SCR10 and SCR11 files. If numerous water rights involving multiple-reservoir system operations are included in a simulation, the scratch files may be used quite extensively. A RAM (random-access memory) disk can be used to increase the computational speed.

The WRAP3 optional ROOT.SYS and ROOT.ADJ output files are created only if specified on the JD record of the input file.

A WRAP input filename (ROOT.DAT) has a user-defined root and the extension "DAT." The ROOT.DAT file may contain all the input records, including the title (T1, T2, T3) records through the hydrology (IN and EV) records (as defined in Appendix A). Since input files can be quite voluminous, WRAP3 provides the option of dividing the data into two files, ROOT.DAT and ROOT.HYD. The streamflow (IN) and evaporation (EV) records are stored in the hydrology file, ROOT.HYD, and all other records in the other file, ROOT.DAT. With this option, the ROOT.DAT file ends with the ED record.

Model execution begins with an interactive routine for defining the pertinent input and output files. The user responds to a series of prompts, involving either entering file names or yes/no responses. Either a Y, y, N, or n can be entered for a yes-or-no response or the default "yes" can be selected by simply pressing return. Only the root of the file names and, if desired, the drive and directory path, are entered for the WRAP programs, with the extensions being automatically assigned by the program. The complete file names, including extensions, are entered for TABLES.

Table 7  
**Computer Files**

## Fortran Program Files and Executable Program Files

WRAP2.FOR	WRAP2.EXE
WRAP3.FOR	WRAP3.EXE
TABLES.FOR	TABLES.EXE

## WRAP Input Files

ROOT.DAT - WRAP2 or WRAP3 input file (unit=3)  
ROOT.HYD - WRAP3 optional hydrology input file (unit=12)

## WRAP Output Files

ROOT.OUT - WRAP2 or WRAP3 main output file (unit=4)  
ROOT.ERR - WRAP2 or WRAP3 error file (unit=14)  
ROOT.SYS - WRAP3 optional multireservoir system file (unit=13)  
ROOT.ADJ - WRAP3 optional negative incremental flows (unit=9)  
SCR10 & - WRAP3 temporary scratch files used during the computations (unit=10,11)  
SCR11

## TABLES Input Files

ROOT.EXT - TABLES input file (unit=1)  
ROOT.DAT - WRAP input file (unit=3)  
ROOT.OUT - WRAP output file (unit=4)  
ROOT.SYS - WRAP3 system file (unit=5)

## TABLES Output File

ROOT.EXT - TABLES output file (unit=2)

## REFERENCES

- Dunn, D.D., "Incorporation of System Operation Strategies in Water Rights Modeling and Analysis," Master of Science Thesis, Texas A&M University, August 1993.
- Getches, D.H., Water Law, West Publishing Company, St. Paul, Minnesota, 1990.
- Rice, L., and White, M.D., Engineering Aspects of Water Law, John Wiley and Sons, 1987.
- Sanchez-Torres, G., "Reservoir System Reliability Considering Water Rights and Water Quality," Ph.D. Dissertation, Texas A&M University, December 1994.
- Walls, W.B., "Application of a Water Rights Analysis Program to Reservoir System Yield Calculations," Master of Science Thesis, Texas A&M University, August 1988.
- Wurbs, R.A., Bergman, C.E., Carriere, P.E., and Walls, W.B., "Hydrologic and Institutional Water Availability in the Brazos River Basin," Technical Report 144, Texas Water Resources Institute, August 1988.
- Wurbs, R.A., and Walls, W.B., "Water Rights Modeling and Analysis," *Journal of Water Resources Planning and Management*, American Society of Civil Engineers, Volume 115, Number 4, July 1989.
- Wurbs, R.A., G. Sanchez-Torres, and D.D. Dunn, "Reservoir/River System Reliability Considering Water Rights and Water Quality," Technical Report 165, Texas Water Resources Institute, March 1994.
- Wurbs, R.A., "Water Rights in Texas," *Journal of Water Resources Planning and Management*, American Society of Civil Engineers, Vol. 121, No. 6, November/December 1995.
- Wurbs, R.A., and G. Sanchez-Torres, "Simulation of a Surface Water Allocation System," *Water International, Journal of the International Water Resources Association*, Vol. 21, No. 1, March 1996.
- Wurbs, R.A., "San Jacinto River Basin Water Availability Model," contract report, Texas Natural Resource Conservation Commission, September 1996.
- Yerramreddy, A.R., "Comparative Evaluation of Network Flow Programming and Conventional Reservoir System Simulation Models," Master of Science Thesis, Texas A&M University, August 1993.
- Yerramreddy, A.R., and R.A. Wurbs, "Water Resources Allocation Based on Network Flow Programming," *Journal of Civil Engineering Systems*, Gordon and Breach Publishers, Vol. 13, No. 1, 1996.

## APPENDIX A

### DESCRIPTION OF INPUT RECORDS FOR WRAP2 AND WRAP3

The first two characters of each record consist of the record identifier. The records are arranged in an input file in generally the same order as cited below. The records have a maximum length of 80 characters. The title and comment records (T1, T2, T3, \*\*) include the two-character identifier and a 78-character alphanumeric (AN) field. All other records are divided into 11 fields, some of which may not be used for a particular record. The first field is the two-character record identifier. The second field has a width of 6 characters. All other fields have a width of 8 characters. Variables with integer (I) or character (A) format specifications must be right-justified in the appropriate field. Real (F format) variables must either include the decimal or be right-justified.

#### T1, T2, or T3 Record - Titles or Headings - Required - WRAP2, WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	T1,T2,T3	record identifier
2	TITLE1 TITLE2 TITLE3	A78	AN	title or heading

#### \*\* Record - Comments - Optional - WRAP2, WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	**	record identifier
2	-	A78	AN	comment

#### JD Record - Job Control - Required - WRAP2

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	JD	record identifier
2	NYRS	I6	+	number of years in simulation
3	NPRDS	I8	+	number of periods (months) per year
4	YRST	I8	+	year in which to start simulation. All IN and EV records prior to YRST will be skipped.
5	NCPTS	I8	+	number of control points listed on CP records
6	NWRTS	I8	+	number of water rights listed on WR records
7	NUSES	I8	+	number of use types listed on UC records

## DESCRIPTION OF INPUT RECORDS FOR WRAP2 AND WRAP3 (Continued)

### JD Record - Job Control - Required - WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	JD	record identifier
2	NYRS	I6	+	number of years in simulation
3	NPRDS	I8	+	number of periods (months) per year
4	YRST	I8	+	year in which to start simulation. All IN and EV records prior to YRST will be skipped.
5	POWFCT	F8.0	BLANK,0	Default value of 0.0010237 will be used for multiplication factor when computing hydroelectric energy.
			+	hydropower multiplication factor
6	ADJINC	I8	BLK,0,1	negative incremental inflow option 1
			2	option 2
			3	option 3
			4	option 4
7	STOFLG	I8	BLANK,0	end-of-period storage used when making system release decisions from secondary reservoirs.
			1	beginning-of-period storage used
8	GPOUT	I8	BLANK,0	water right identifiers output for chosen water rights
			1	group identifiers output for chosen water rights
9	ADJOUT	I8	BLANK,0	negative incremental streamflow adjustment file will not be written
			1	file will be written
10	SYSOUT	I8	BLANK,O	system release/hydropower file will not be created
			1	output file is written
11	CPOUT	I8	BLANK,O	control point records are written to output file
			1	control point records are not written to output file

### JG Record - Water Right Groups for Output - One Required - WRAP2, WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>identifier</u>
1	CD	A2	JG	record identifier
2	NGOUT	I6	BLANK,0	no water rights will be output
			-1	all water rights will be output
			1-60	number of water right group identifiers listed on JG records, five on each record
3-7	GROUP(1,5)	5A8	AN	identifiers of water rights and groups for output. Field 2 is blank for the second and subsequent JG records.

## DESCRIPTION OF INPUT RECORDS FOR WRAP2 AND WRAP3 (Continued)

### JR Record - Reservoirs for Output - One Required - WRAP2, WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>identifier</u>
1	CD	A2	JR	record identifier
2	NREOUT	I6	BLANK,0 -1 1-60	no reservoirs will be output all reservoirs will be output number of reservoir identifiers listed on JR records, five on each record
3-7	REOUID(1,5)	5A8	AN	reservoir identifiers for output. Field 2 is blank for the second and subsequent JR records.

### UC Record - Monthly Use Factors - One Required - WRAP2, WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	UC	record identifier
2	USEID(I)	A6	AN	identifier of use type
3-8	PDUSCF(I,J=1,6)	6F8.0	+	monthly use coefficients. Six entered on first UC record, six on second. Field 2 is blank on second UC record.

Index I goes from 1 to NUSES. J index goes from 1 to 12.

### CP Record - Control Point Information - One Required - WRAP2, WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	CP	record identifier
2	CPID(I,1)	A6	AN	control point identifier
3	CPID(I,2)	A8	AN ' OUT'	identifier of next downstream control point no control points are downstream
4	CPDT(I,1)	F8.0	BLANK,0 +	no inflow multiplier will be used for inflows at this control point. factor to multiply inflows listed on IN records
5	CPDT(I,2)	F8.0	BLANK,0 +	no evaporation multiplier used evaporation multiplier.

Index I goes from 1 to NCPTS.

## DESCRIPTION OF INPUT RECORDS FOR WRAP2 AND WRAP3 (Continued)

### WR Record - Water Right Record - One Required - WRAP2

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	WR	record identifier
2	FILEID(I,1)	A6	AN	water right identifier
3	FILEID(I,2)	A8	AN	control point identifier
4	FILE11(I,1)	F8.0	0,+	annual permitted diversion
5	FILEID(I,3)	A8	AN	use type identifier
6	DATE(I)	I8	+	priority number/date
7	NONE	8X	-	blank field
8	FILE11(I,5)	F8.0	+	return flow factor. Return flows returned in same month.
			-	return flow factor. Return flows returned in next month.
			0.	no return flow or flow returned out of basin
9	FILEID(I,5)	A8	BLANK	flow returned to next downstream control point
			AN	identifier of control point to return flow
10	GP	A8	BLANK	no group identifier
			AN	group identifier for water right.
11	IWS	BLANK	watershed	flow option is not used
		F8.5	+	drainage area ratio or other multiplier
		I6	-	watershed flow option identifier linked to FL record

Index I goes from 1 to NWRTS.

### WR Record - Water Right Record - One Required - WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	WR	record identifier
2	WRID(I)	A6	AN	water right identifier, subscript "I" goes from 1 to NWRTS
3	CP	A8	AN	control point identifier
4	AMT	F8.0	0,+	annual permitted diversion
5	USE	A8	AN	use type identifier
6	WRNUM(I,7)	I8	+	priority number/date



## DESCRIPTION OF INPUT RECORDS FOR WRAP2 AND WRAP3 (Continued)

### WR Record - Water Right Record - One Required - WRAP3 (Continued)

7	WRNUM(I,5)	I8	BLANK,0,1	type 1 water right 2 type 2 water right 3 type 3 water right 4 type 4 water right -1 hydropower right
8	RFAC	F8.0	+	return flow factor. Return flow returned in same month
			-	return flow factor. Return flow returned in next month.
			0	no return flow or flow returned out of basin
9	RCP	A8	BLANK	return flow returned to next downstream control point
			AN	identifier of control point to return flow
10	CP	A8	BLANK	no group identifier
			AN	group identifier for water right.
11	IWS	I6	BLANK	watershed flow option is not used
		F8.5	+	drainage area ratio or other multiplier
		I6	-	watershed flow option identifier linked to FL record

### WS Record - Water Right Reservoir Storage - Optional - WRAP2

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	WS	record identifier
2	FILEID(I,4)	A6	AN	reservoir identifier
3	FILE11(I,4)	F8.0	+	storage capacity of right
4	EVCFA	F8.0	+	first storage-area coefficient
			-	storage-area table entered for this reservoir
5	EVCFB	F8.0	+	second storage-area coefficient
6	EVCFC	F8.0	+	third storage-area coefficient

Fields 4, 5, and 6 are blank if reservoir is listed on a previous WS record.

## DESCRIPTION OF INPUT RECORDS FOR WRAP2 AND WRAP3 (Continued)

### WS Record - Water Right Reservoir Storage - Optional - WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	WS	record identifier
2	RES	A6	AN	reservoir identifier
3	WRSYS(I,3)	F8.0	+	storage capacity
4	EVCFA	F8.0	+	first storage-area coefficient (equation below)
			-	storage-area table entered on SV and SA records
5	EVCFB	F8.0	+	second storage-area coefficient
6	EVCFB	F8.0	+	third storage-area coefficient
7	WRSYS(I,1) or WRSYS(I,2)	F8.0	+	storage capacity at top of inactive pool (bottom of active pool) or storage capacity at bottom of power pool (hydropower right)
8	RESDAT(I,5)	F8.0	BLANK,0	reservoir is full to capacity (field 3) at beginning of simulation
			+	volume in storage at beginning of simulation
9	WRSYS(I,1)	F8.0	+	tailwater elevation for hydropower
10	WRSYS(I,4)	F8.0	+	water-to-wire efficiency for hydropower
11	SYSNUM(I,3)	I8	BLANK,0	downstream releases flow through hydropower turbines
			-	lakeside withdrawals do not flow through hydropower turbines

$$\text{area} = \text{EVCFA} * \text{storage} ** \text{EVCFB} + \text{EVCFB}$$

Fields 4, 5, and 6 can be left blank if the reservoir is listed on a previous WS record. Fields 9 and 10 are blank except for hydropower. Field 11 pertains to water rights involving releases which may affect some other hydropower right.

### OR Record - Multiple-Reservoir Operating Rules-Optional-WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	OR	record identifier
2	CP	A6	AN	control point identifier for reservoir
3	WRSYS(I,2)	F8.0	+	storage capacity at top of zone 2 (bottom of zone 1)
4	WRSYS(I,5)	F8.0	+	zone 1 release priority factor
5	WRSYS(I,4)	F8.0	+	zone 2 release priority factor

## DESCRIPTION OF INPUT RECORDS FOR WRAP2 AND WRAP3 (Continued)

### OR Record - Multiple-Reservoir Operating Rules-Optional-WRAP3 (Continued)

6	SYSNUM(I,2)	I8	BLANK,0	releases constrained to gravity flow in river channels
			-	pump and pipeline conveyance as well as river flow

An OR record is required, in addition to a WS record, for each secondary reservoir associated with the water right (WR record). Field 2 can optionally be left blank if the control point identifier (CP) has been assigned to the reservoir identifier (RES) by a previous water right.

### WI Record - Storage-Flow Data for Type 4 Right - Optional - WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	WI	record identifier
2	STOFLO(I,1)	F6.0	0	no reservoir releases
			-	no limit on reservoir releases
			+	limit on reservoir releases expressed as a decimal fraction of naturalized streamflow at the water right location
3	STOFLO(I,2)	F8.0	+	reservoir system storage content permitted
4	STOFLO(I,3)	F8.0	+	diversion amount
5	STOFLO(I,4)	F8.0	+	reservoir system storage content
6	STOFLO(I,5)	F8.0	+	permitted diversion amount
7	STOFLO(I,6)	F8.0	+	reservoir system storage content
8	STOFLO(I,7)	F8.0	+	permitted diversion amount
9	STOFLO(I,8)	F8.0	+	reservoir system storage content
10	STOFLO(I,9)	F8.0	+	permitted diversion amount

- Subsequent pairs are entered on second and third WI records. Field 2 is blank on second and third WI records. Maximum of 12 pairs may be entered. Subscript I represents index of type 4 right. A maximum of 50 type 4 rights may be entered.

## DESCRIPTION OF INPUT RECORDS FOR WRAP2 AND WRAP3 (Continued)

### SV Record - Storage-Area Table Volumes - Optional - WRAP2, WRAP3

- Two SV records must be entered for each table.

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	SV	record identifier
2	RES	A6	AN	reservoir identifier if first SV record
	-		BLANK	if second SV record
3-8	TARA(1-6) TARA(7-12)	6F8.0	+	volumes on storage-area table

### SA Record - Storage-Area Table Areas - Optional - WRAP2, WRAP3

- Two SA records must be entered for each table immediately following the SV records.

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	SA	record identifier
2	-	6X	BLANK	for both SA records
3-8	TARB(1-6) TARB(7-12)	6F8.0	+	areas on storage-area table

### PV Record - Storage-Elevation Table Volumes - Optional - WRAP3

- Identical format as SV record

### PE Record - Storage-Elevation Table Elevations - Optional - WRAP3

- Identical format as SA record

## DESCRIPTION OF INPUT RECORDS FOR WRAP2 AND WRAP3 (Continued)

FL Record - Watershed Flow - Optional - WRAP2, WRAP3

- One FL record for each watershed flow identifier (IWS) specified in field 11 of water rights (WR) records. All FL records are grouped together in any order just before the end-of-data (ED) record. Input parameters are input for the equations shown below.

$$F_{WR} = aS^b + cB + C$$

$$S = F_{CP} - B$$

$$B = L \quad \text{if } F > L$$

$$B = F_{CP} \quad \text{if } F_{CP} < L$$

$$F_{CP} = \text{FLOW1} - \text{FLOW2} - \text{FLOW3}$$

- F = computed flow at water right location [FLAMT]
- S<sup>WR</sup> = computed storm runoff [STORM]
- B = computed base flow [BASE]
- L = input limit between base flow and storm runoff [FL(IWS,5)]
- C = input constant flow [FL(IWS,4)]
- a = input coefficient [FL(IWS,1)]
- b = input exponent [FL(IWS,2)]
- c = input coefficient [FL(IWS,3)]
- F = naturalized streamflow at input for control point(s) [CPFLOW]
- FLOW1 = flow at downstream control point [FLCP(IWS,1)]
- FLOW2 = flow at downstream control point [FLCP(IWS,2)]
- FLOW3 = flow at downstream control point [FLCP(IWS,3)]

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	IN	record identifier
2	IWS	I8	+	identifier from field 11 of WR record
3	FL(IWS,1)	F8.5	+	coefficient "a" in above equation
4	FL(IWS,2)	F8.5	+	exponent "b"
5	FL(IWS,3)	F8.5	+	coefficient "c"
6	FL(IWS,4)	F8.1	+	limit "L" between base flow and runoff
7	FL(IWS,5)	F8.1	+,-	constant C
8	FLCP(IWS,1)	A6	AN	downstream control point
9	FLCP(IWS,2)	A6	AN	upstream control point
10	FLCP(IWS,3)	A6	AN	upstream control point

## DESCRIPTION OF INPUT RECORDS FOR WRAP2 AND WRAP3 (Continued)

ED Record - End of Data for Basin Description - Required - WRAP2, WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	ED	record identifier

IN Record - Naturalized Streamflow at Control Points - Required - WRAP2, WRAP3

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A2	IN	record identifier
2	CPIN(J)	A6	AN	control point identifier
3	PYR	I8	+	year of inflow
			-	year of inflows, but inflows equal inflows at control point identifier listed on field 4
4-9	INFLO(i,1-6)	6F8.0	0,+	inflows at control point for months 1-6 of year PYR
4	REPEAT	A6	AN	if PYR=negative, identifier of control point to set inflows equal to

- On second IN record for a control point, fields 2 and 3 are blank, and inflows for months 7-12 are in fields 4-9. A second IN record is not required if PYR=negative. IN records for all control points for a year must be entered before the EV records for that year.

EV Record - Net Evaporation Rate at Control Point - Required - WRAP2, WRAP3

- The format of EV records is identical to IN records except evaporation rates are entered instead of streamflows.
- IN records for a year for all control points are grouped together followed by all the EV records grouped together for the year.
- For a given year, the IN records for each control point can be in any order. Likewise, the control point order of the EV records is arbitrary.

## APPENDIX B DESCRIPTION OF INPUT RECORDS FOR TABLES

The first four characters of each record consists of the record identifier. TITL records are placed at the beginning of the file. No more than five TITL records can be used. The ENDF record is the last record read. Any records placed after an ENDF record will not be read. With the exceptions of the TITL and ENDF records just mentioned, the records can be placed in any order. Any type of record can be used any number of times. All records are optional. There are no required records.

2SCP, 2SWR, 2SRE, 2NAT, 2UNA, 2DEP, 2SHT, 2STO, 2SRE, 2PER, 4SWR, and 4SGP records include the optional variable (IDEN(ID,I),I=1,NUM). Only eight values of IDEN can be entered on one record. Therefore, if NUM is greater than eight, the remaining values of IDEN are entered in fields 4-11 of subsequent records immediately following the first record. For NUM greater than 8, fields 2 and 3 of the second and subsequent records are not read. After (IDEN(ID,I), I=1,NUM) is entered one time, subsequent records can use the same IDEN identifiers, without reentering, by entering a negative value for NUM.

With the exception of TITL and COMM records, all data provided in a TABLES input file should be right-justified in each field.

### TITL Record - Titles or Headings

From zero to five TITL records are entered as the first records of the input file. The alphanumeric information provided on the records is printed on the cover page and at the top of each table.

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	TITL	record identifier
2	TITLE	A76	AN	title or heading

### COMM Record - Comments

Any number of COMM records can be inserted anyplace in the input file to provide notes or comments. The COMM records are not read or used in any way by the program.

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	COMM	record identifier
2	-	A76	AN	input file comment or note

### PAGE Record - Title Page

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	PAGE	prints title page

## DESCRIPTION OF INPUT RECORDS FOR TABLES (Continued)

### ENDF Record - End of Input Data File

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	ENDF	record identifier

### 1REC Record - Listing of Specified WRAP Input Records

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	1REC	record identifier
2	KK	I4	0	list specified records
			nonzero	list all records except specified records
3	NUM	I4	+	number of record identifiers to follow
4-20	REC	17A4	AN	identifiers of specified WRAP input records (REC(I),I=1,NUM)

### 1SUM Record - Water Rights Summary

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	1SUM	record identifier
2	KK	I4	1	summary by control point
			2	summary by type of use
			3	summary by water right type
			4	summary by water right group

### 1SRT Record - Listing of Sorted Water Rights

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	1SRT	record identifier
2	KK	I4	0	listing of rights in priority order
			1	listing of rights by control point in priority order
			2	listing of rights by type-of-use in priority order
			3	listing of rights by water right type in priority order
			4	listing of rights by water right group in priority order



## DESCRIPTION OF INPUT RECORDS FOR TABLES (Continued)

### 2SCP Record - Summary Table for a Control Point

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	2SCP	record identifier
2	MNAN	I4	0	annual table
			1	monthly table
			2	both annual and monthly tables
3	NUM	I4	0	develop tables for all control points
			BLANK	if NUM is zero or negative
			-	develop tables for NUM control points listed on a previous record
			+	number of control points to follow
4-11	IDEN	8A8	AN	identifiers of control points for which to develop tables (IDEN(ID,I),I=1,NUM)

### 2SWR Record - Summary Table for a Water Right

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	2SWR	record identifier
2	MNAN	I4	0	annual table
			1	monthly table
			2	both annual and monthly tables
3	NUM	I4	0	develop tables for all water rights
			-	develop tables for NUM water rights listed on a previous record
			+	number of water rights to follow
4-11	IDEN	8A8	AN	identifiers of water rights for which to develop tables IDEN(ID,I),I=1,NUM)
			BLANK	if NUM is zero or negative

### 2SRE Record - Summary Table for a Reservoir

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	2SRE	record identifier
2	MNAN	I4	0	annual table
			1	monthly table
			2	both annual and monthly tables
3	NUM	I4	0	develop tables for all reservoirs
			-	develop tables for NUM reservoirs listed on a previous record
			+	number of reservoirs to follow

## DESCRIPTION OF INPUT RECORDS FOR TABLES (Continued)

### 2SRE Record - Summary Table for a Reservoir (Continued)

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
4	IDEN	8A8	AN	identifiers of reservoirs for which to develop tables (IDEN(ID,I),I-1,NUM) BLANK if NUM is zero or negative

### 2SGP Record - Summary Table for a Water Right Group

Same as 2SWR record except CD is 2SGP and IDEN denotes water right group identifiers. Water right groups must be listed explicitly. NUM cannot be zero for any water right group operation.

### 2SBA Record - Summary Table for River Basin (All Control Points)

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	2SBA	record identifier
2	MNAN	I4	0 1 2	annual table monthly table both annual and monthly tables

### 2REL Record - Reliability and Shortage Summary

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	2REL	record identifier
2	ID	I4	0 1 2 3	table includes selected control points table includes selected water rights table includes selected hydropower reservoirs table includes selected water right groups
3	NUM	I4	0 - +	include all control points (ID=0), water rights (ID=1), or reservoirs (ID=2) in table include NUM previously listed control points, water rights, reservoirs or water right groups in table number of control points, water rights, reservoirs or water right groups to follow
4-11	IDEN	8A8	AN	identifiers of control points (ID=0), water rights (ID=1), reservoirs (ID=2) or water right groups (ID=3) to include in table (IDEN(ID,I),I=1,NUM) BLANK if NUM is zero or negative

## DESCRIPTION OF INPUT RECORDS FOR TABLES (Continued)

2NAT Record - Naturalized Streamflow Table  
 2UNA Record - Unappropriated Streamflow Table  
 2DEP Record - Streamflow Depletion Table  
 2SHT Record - Shortage Table  
 2STO Record - Storage Table

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	2NAT 2UNA 2DEP 2SHT 2STO	record identifier
2	ID	I4	0 1 2 3	develop tables for control points develop tables for water rights develop tables for reservoirs develop tables for water right groups
3	NUM	I4	0 - +	develop table for all control points (ID=0), water rights (ID=1), or reservoirs (ID=2). NUM cannot be zero if ID=3. develop tables for NUM previously listed control points, water rights, or reservoirs number of control points, water rights, reservoirs, or water right groups to follow
4-11	IDEN	8A8	AN  BLANK	identifiers of control points (ID=0), water rights (ID=1), reservoirs (ID=2), water right groups (ID=3) to include in table (IDEN(ID,I),I-1,NUM) if NUM is zero or negative

2PER Record - Percent Storage and Storage-Duration Records

First 2PER Record (Fields 3-10 are continued on a second record for more than eight reservoirs. A maximum of 12 reservoirs can be included.)

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	2PER	record identifier
2	NUM	I8	+ -	number of reservoirs reservoir identifiers previously entered
3-10	IDEN	8A8	AN	reservoir identifiers

## DESCRIPTION OF INPUT RECORDS FOR TABLES (Contin-

ued)

### Subsequent 2PER Records (four reservoirs per record)

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	2PER	record identifier
2	-	8X	-	blank or comment
3	CAP	F8.0	+	inactive capacity in first reservoir
4	CAP	F8.0	+	total capacity in first reservoir
5	CAP	F8.0	+	inactive capacity in second reservoir
6	CAP	F8.0	+	total capacity in second reservoir
7	CAP	F8.0	+	inactive capacity in third reservoir
8	CAP	F8.0	+	total capacity in third reservoir
9	CAP	F8.0	+	inactive capacity in fourth reservoir
10	CAP	F8.0	+	total capacity in fourth reservoir

### First 3HEC Record

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	3HEC	record identifier
2	HEC	I4	3	HEC-3 format for IN and EV records
			5	HEC-5 format for IN and EV records
3	EV	I4	0	evaporation rate (EV) records are not included in output
			1	EV records are included
4	NEGYR	I4	0	“negative year” messages written
			+	“negative year” messages not written
5	IN	I4	1	unappropriated flows are output on IN records
			2	unappropriated flows plus streamflow depletions are output on IN records
			3	streamflow depletions are output on IN records
			4	naturalized streamflows are output on IN records
6	CPTS	I4	+	number of control points to include in output. A 3HEC record follows for each of CPTS control points
7	EVFAC	F8.4	BLANK	EVFAC=1.0
			+	factor by which evaporation rates are multiplied
8	INFAC	F8.4	BLANK	INFAC=1.0
			+	factor by which streamflows are multiplied

## DESCRIPTION OF INPUT RECORDS FOR TABLES (Continued)

### Second and Subsequent 3HEC Records for Each Control Point

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	3HEC	record identifier
2	-	4X	AN	comment, not read by program
3	CPID	A8	AN	WRAP control point identifier
4	INCP	I4	+	control point identifier on HEC IN record
5	EVCT	I4	+	evaporation control point counter
6	EVID	I4	+	reservoir identifier on HEC EV record
7	NUM	I4	+	number of water rights
8-13	IDEN	6A8	AN	identifiers of water rights to include in streamflow depletion summation at this control point (IDEN(I,J),J=1,NUM)

### 3NAT Record - Naturalized Streamflows and Evaporation Rates in HEC Format

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	3NAT	record identifier
2	HEC	I4	3	HEC-3 format for IN and EV records
			5	HEC-5 format for IN and EV records
3	EV	I4	0	evaporation rate (EV) records are not included in output
			1	EV records are included
4	NEGYR	I4	0	“negative year” messages written
5	EVFAC	F8.4	BLANK	EVFAC=1.0
			+	factor by which evaporation rates are multiplied
6	INFAC	F8.4	BLANK	INFAC=1.0

### 3UNA Record - Unappropriated Streamflows and Evaporation Rates in HEC Format

Same as 3NAT record except CD is 3UNA

### 3DEP Record - Streamflow Depletions and Evaporation Rates in HEC Format

Same as 3NAT record except CD is 3DEP

## DESCRIPTION OF INPUT RECORDS FOR TABLES (Continued)

### 4SWR Record - System Reservoir Release Summary for a Water Right

<u>field</u>	<u>variable</u>	<u>format</u>	<u>value</u>	<u>description</u>
1	CD	A4	4SWR	record identifier
2	MNAN	I4	0 1 2	annual table monthly table both annual and monthly tables
3	NUM	I4	+	number of water rights to follow
4	FIRST	I4	0, BLANK	include the first 15 reservoirs associated with water right identifier in field 5 in the order listed on WS records in the WRAP3 input file
			+	include the FIRST reservoir associated with water right identifier in field 5 and the next 14 reservoirs in the order listed on WS records in the WRAP3 input file
5	IDEN	A8	AN	identifier of water right for which to develop system reservoir release tables
6	FIRST	I4	0, BLANK	include the first 15 reservoirs associated with water right identifier in field 7 in the order listed on WS records in the WRAP3 input file
			+	include the FIRST reservoir associated with water right identifier in field 7 in the order listed on WS records in the WRAP3 input file
7	IDEN	A8	AN	identifier of water right for which to develop system reservoir release tables
8	FIRST	I4	0, BLANK	same as above
			+	
9	IDEN	A4	AN	
10	FIRST	I4	0, BLANK	
11	IDEN	A4	AN	
12	FIRST	I4	0, BLANK	
13	IDEN	A4	AN	

### 4SGP Record - System Reservoir Release Summary Table for a Water Right Group

Same as a 4SWR record except CD is 4SGP, and IDEN denotes a water right group. For both 4SWR and 4SGP, NUM (field 3) must be a positive nonzero integer and the identifiers (fields 5, 7, 9, 11, 13) must be listed explicitly.

## APPENDIX G

### GUIDELINES FOR DEVELOPING WRAP INPUT

A model for a particular river basin (or multiple-basin region) consists of the WRAP software combined with the input file developed for the particular basin. The content and format for the input file is outlined in the main report and previous appendices. The following guidelines focus on compiling the information needed to develop a WRAP2/WRAP3 input file.

Numerous policy issues are inherent in water availability modeling. These issues involve various aspects of water management such as meeting instream flow needs, effects of return flows on water availability, reservoir storage priorities, multiple-reservoir system operations, reservoir sedimentation, and drought management including procedures for curtailing water use during droughts. Collection and management of data on streamflows, evaporation, water management, and water use are also major concerns. Resolution of policy issues and compilation of the required data are prerequisite to computer modeling. The generalized WRAP modeling system provides flexible capabilities for simulating a river basin for user-specified hydrology, water management scenario, and modeling premises.

WRAP simulates management and use of the water resources of a river basin or multiple-basin region under a priority-based water allocation system. With ingenuity and judgement, the model can be applied to various types of river/reservoir/use systems to support a variety of decision processes.

The model is designed specifically for the Texas water rights system but can be applied elsewhere as well. The public-domain software package is generalized for application in any river basin, with input data files being developed for the particular river basin of concern. The original version of this set of guidelines was prepared for the Texas Natural Resource Conservation Commission. Although the discussion is oriented toward applications in Texas, the guidelines are generally pertinent for various model users regardless of their particular types of modeling situations or the locations of their river basins.

#### **Water Rights Modeling in Texas**

The Texas Water Commission (TWC) and Texas Department of Water Resources (TDWR), which were predecessors of the TNRCC, developed water availability models for several major river basins during the 1970's and 1980's in support of the water rights adjudication process. Although the simulation models are no longer being executed, their input and output data continue to be used. The Texas Natural Resource Conservation Commission (TNRCC) is updating these earlier models using the Water Rights Analysis Package (WRAP). Information from the earlier TWC/TDWR water availability models is available through the TNRCC for the river basins which are listed in Table G-1. The table includes the date of the latest version of each model and the hydrologic period-of-analysis incorporated in the model.

The Brazos River Basin served as a case study for the university research projects in which the generalized WRAP model was developed. The TNRCC applied WRAP to the Lavaca and San Jacinto River Basins in 1996. Reports and journal papers cited in the *References* section (page 59) provide examples of applying WRAP.

Table G-1  
Water Availability Models Developed Earlier by the  
Texas Water Commission or Texas Department of Water Resources

<u>River Basin</u>	<u>Model Date</u>	<u>Simulation Period</u>
Brazos	Feb 1987	1940-1976
Colorado	Oct 1979	1940-1972
Guadalupe	Mar 1983	1940-1979
Lavaca	Jul 1982	1940-1979
Nueces	Mar 1982	1940-1978
San Antonio	Mar 1983	1940-1979
San Jacinto	Jun 1983	1940-1980
Trinity	Oct 1990	1940-1981

Much of the information required to develop a WRAP input file is available from the input and output of the earlier water availability models. The Interactive Water Rights Retrieval (IWR) System is a TNRCC database for managing the data from the water availability models. Current water rights information is also maintained by the TNRCC.

### **Steps in Developing WRAP Input for a River Basin**

Developing the necessary WRAP input information consists of the following major tasks or steps, which are discussed in subsequent sections of this appendix.

1. Delineation of the spatial configuration of the river/reservoir/rights system as a set of control points.
2. Compilation of basin hydrology consisting of:
  - sequences of monthly naturalized streamflows for each control point,
  - for remote water right locations, drainage area ratios or other parameters for determining naturalized flows as a function of flows at control points, and
  - net reservoir evaporation rates.
3. Compilation of water rights information including:
  - annual diversion amounts, storage capacities, water use types, and priority dates specified in each water right permit,
  - monthly water use factors for distributing annual amounts over the year,
  - return flow specifications,
  - instream flow requirements,
  - hydroelectric energy generation requirements,
  - reservoir storage volume versus water surface area relationships,
  - reservoir water surface elevation versus storage volume and tailwater elevation versus discharge relationships for reservoirs operated for hydroelectric power, and
  - operating rules for any reservoirs operated as a multiple-reservoir system.



## **Spatial Configuration**

Selection of a set of control point locations is an initial task in developing a WRAP input file. The spatial configuration of the river basin is delineated by specifying the next control point located just downstream of each control point. The location of streamflows, evaporation rates, diversions, return flows, reservoirs, and other system features are specified by control point. Naturalized streamflows are provided as input for all control points, and the model computes unappropriated streamflows and other quantities for each control point location.

Judgement is required to select a set of control points that adequately define the locations of important system features while not unduly complicating the model. A key consideration is that naturalized streamflows for all control points must either be provided as input or expressed as a function of flows at other control points. Water rights, reservoirs, and other system components must be located on maps and assigned control points.

The concept of a network of control points is analogous to the system of watersheds and subwatersheds adopted in the earlier TWC and TDWR water availability models. U.S. Geological Survey gaging station locations were typically designated as watershed outlets in the earlier water availability models since streamflow data were available there. Likewise, stream gage locations continue to be used as WRAP control points. Other control points are designated as required to define the location of the major components of the river basin/water rights system. In updating the TWC/TDWR models, the control points will often correspond to the TWC/TDWR model watershed outlets and, in some cases, subwatershed outlets. Other subwatersheds will be represented by the watershed flow option noted below.

Water right diversions and storage typically occur at many remote ungaged locations throughout the watersheds above the control points. The October 1996 version of WRAP2 and WRAP3 includes a watershed flow option to supplement 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. The watershed flow option is used for rights located some distance from their assigned control points. The WRAP model limits water available to these rights to the lesser of naturalized streamflows at the site or yet unappropriated flows at downstream control points. The watershed flow option allows naturalized streamflows at the watershed sites to be determined as a function of the flows provided as input for a specified control point or alternatively as a function of incremental flows between specified control points. The watershed flow option provides flexibility for determining the flows at the water right location in different ways ranging from simply using a drainage area ratio to more complex functional relations requiring input of several parameters.

## **Basin Hydrology**

Basin hydrology consists of naturalized streamflows and net reservoir evaporation rates for each month of the simulation provided as WRAP input. Naturalized streamflows are required for all control points. Evaporation rates are required for any control point at which a reservoir is located. WRAP allows naturalized flows and evaporation rates at a control point to be computed within the model by multiplying data input for that location or another location by a user-specified factor. Natu-

ralized streamflows (inflows) and evaporation rates are recorded on IN and EV records in a WRAP input file. WRAP allows all input to be provided in a single file, or alternatively the IN and EV records can be input as a separate hydrology file.

### Naturalized Streamflows

Naturalized streamflows represent flows that would have occurred in the absence of water resources development and use in the basin. Naturalized flows are developed by adjusting historical gaged flows. Regression analyses are used to extend flow records and reconstitute months of missing data in the records.

A systematic methodology, with computer software and data compilation procedures, is currently needed for developing sequences of naturalized streamflows based on gaged flow records. WRAP provides no capabilities for adjusting gaged streamflows to develop the naturalized streamflows input on inflow (IN) records. The authors know of no readily-available generalized computer programs for naturalizing gaged streamflows. Such computations are common but generally have been performed on an ad hoc study-by-study basis.

Computer programs, such as the Texas Water Development Board *MOSS-IV Monthly Streamflow Simulation* model, are available for filling in gaps and extending records based on regression analyses.

Development of naturalized streamflows was a major component of the water availability models developed by the TWC and TDWR during the 1970's-1980's. As indicated in Table G-1, a period-of-analysis was adopted for these models beginning in 1940 and ending sometime between 1972 and 1981. These naturalized streamflows are available from the TNRCC Interactive Water Rights Retrieval System (IWR) database. Initial efforts in developing updated water availability models using WRAP are incorporating these naturalized streamflows from the previous TWC and TDWR models.

The models can be improved by extending the naturalized flows to the present. The general concepts and procedures for naturalizing streamflows used in the past should be continued. However, a systematic methodology needs to be developed, with computer software, data collection procedures, and convenient database management capabilities. The level of detail adopted by the TWC and TDWR in the previous studies will probably not be necessary in the future. The water rights adjudication process necessitated detailed development of naturalized flows at the site of every water right. In a typical river basin, many hundreds of reservoirs and diversions were considered in adjusting gaged flows to obtain naturalized flows. However, in any basin, probably most of the impacts of human activities on historical flows at the gaging stations are caused by less than a hundred of the largest reservoirs and diversions. With completion of the water rights adjudication process, for most applications in the future, adequately accurate naturalized flows can likely be obtained by considering only the major reservoirs, diversions, and return flows.

As noted previously, WRAP2 and WRAP3 include an option for computing naturalized streamflows at a water right site as a function of the naturalized flows provided as input at one or more specified control points. The simplest use of this option consists of applying drainage area ratios to apportion flows. Research is needed to develop improved methodologies for incorporating mean precipitation, Natural Resource Conservation Service (formerly SCS) curve numbers, stream lengths, and other parameters along with drainage area in developing the input parameters for the WRAP streamflow synthesis option. The WRAP watershed flow option also provides a framework for streamflows to be treated as a combination of base flows and storm runoff.