Water Rights Analysis Package (WRAP)

Reference Manual

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CHAPTER 1
INTRODUCTION

Brief Description of WRAP

The *Water Rights Analysis Package (WRAP)* simulates management of the water resources of a river basin, or multiple-basin region, under a priority-based water allocation system, such as the Texas water rights system. The *WRAP* model facilitates assessment of hydrologic and institutional water availability/reliability for existing and proposed water rights. Basinwide impacts of water resources development projects and management strategies may be evaluated. The software package is generalized for application to any river/reservoir/use system, with input files being developed for the particular river basin of concern.

WRAP is a component of the Texas Commission on Environmental Quality (TCEQ) *Water Availability Modeling (WAM) System*. The *WAM System* includes water rights and other related databases, data management software, a geographic information system, and *WRAP* input files and simulation results for the 23 river basins of Texas, as well as the generalized *WRAP* simulation model. The *WRAP* model may be applied either independently or in combination with other components of the *WAM System*. This manual focuses specifically on the generalized *WRAP* simulation model, rather than the overall *WAM System*.

The software package consists of the following Fortran computer programs.

WRAP-SIM is the river/reservoir water allocation/management system simulation model.

TABLES is a post-processor for organizing and displaying *WRAP-SIM* simulation results.

WRAP-HYD is a utility program for developing hydrology input files for *WRAP-SIM*.

WinWRAP is a user interface for applying the programs within *Microsoft Windows*.

The main simulation program *WRAP-SIM* performs the river/reservoir/use system water allocation simulation computations. *WRAP-HYD* assists in developing the hydrology-related portion of the *WRAP-SIM* input that consists of sequences of monthly naturalized streamflows and reservoir net evaporation-precipitation rates. The postprocessor program *TABLES* provides capabilities for organizing and summarizing *WRAP-SIM* simulation results as a variety of user-specified tables and reliability/frequency indices. *WinWRAP* facilitates executing the programs within the *Microsoft Windows* operating system in combination with use of Microsoft programs to access and edit *WRAP* input and output files.

The executable programs are distributed for use on desktop computers operating under Microsoft Windows. The Fortran code is also available. Recent versions of the *WRAP* programs were compiled with the integrated Microsoft Visual Development Environment and Compaq Visual Fortran (Version 6.6, copyright 2000). The code conforms to Fortran 95 standards. The public domain *WRAP* software and documentation may be freely copied.

Application of *WRAP* consists of developing and/or modifying the hydrology and water rights input data sets for the river basin system of concern; executing the model with data reflecting alternative water management scenarios of concern; and analyzing simulation results.

Input data sets for the 23 river basins of Texas are available through the TCEQ *WAM System*. *WRAP* users may modify these data sets to model the alternative water management projects and strategies and water use scenarios being investigated in their studies. For river basins outside of Texas, model users must develop the hydrology and water management input data sets required for their particular applications.

A typical *WRAP* simulation study involves assessing capabilities for meeting specified water management/use requirements during a hypothetical repetition of historical hydrology. For example, for a particular application, the analysts may choose to analyze reliabilities of existing or proposed reservoirs and other facilities to supply year 2003 water needs, with basin hydrology represented by sequences of monthly naturalized streamflows and reservoir net evaporation less precipitation rates at all pertinent locations for each of the 732 months of a 1940-2000 hydrologic period-of-analysis. The model allocates water to meet the year 2003 water use requirements during each sequential month of the 732-month simulation. Frequency and reliability relationships are developed from the simulation results.

WRAP uses a monthly time step with no limit on the number of years in the hydrologic period-of-analysis. Annual water use targets, with seasonal variations over the 12 months of the year, are combined with sequences of naturalized streamflows and reservoir net evaporation less precipitation rates representing basin hydrology. The water use targets may vary as a function of reservoir storage and/or streamflow. Water rights requirements include reservoir storage, water supply diversions, return flows, environmental instream flow needs, and hydroelectric power generation. Volume accounting computations associated with meeting the water rights requirements are performed sequentially for each month of the hydrologic period-of-analysis. The simulation results include sequences of regulated and unappropriated streamflows, diversion targets and shortages, energy generated and energy shortages, reservoir storage levels and evaporation amounts, and other related variables. A variety of reliability and frequency analyses of simulation results provide statistical indices for assessing water availability and reliability.

Scope and Organization of the WRAP Documentation

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

Chapters 1 and 2 and Appendices A, B, and C of this *Reference Manual* provide a general overview of *WRAP*. Chapter 1 introduces the model and its documentation and describes its origins. Chapter 2 covers modeling capabilities, input and output data, and computational procedures, from a general overview perspective. Appendices A and B, respectively, are a list of references cited and glossary of terms used in the manual. *WRAP* has evolved over time with a number of versions having been distributed containing the various modifications outlined in Appendix C.

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

Appendices D, E, and F provide subroutine descriptions, variable definitions, and other information regarding the Fortran programs. These appendices are designed for those interested in examining or modifying the computer code, but are not needed to use the executable programs.

Appendix G consists of input and output for several *WRAP-SIM* and *TABLES* examples. Examples illustrating *WRAP-HYD* are presented as Appendix H. The input files for the examples are distributed in electronic format with the model. The examples are simple hypothetical data sets created to illustrate *WRAP* modeling capabilities and input and output data format. Other input files for actual river basins are also available for use as examples.

<u>**Model Development Background**</u>

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

- to provide capabilities for assessing hydrologic and institutional water availability/reliability within the framework of the priority-based Texas water rights system

- to develop a flexible generalized computer model for simulating the complexities of surface water management, which can be adapted by water management agencies and consulting firms to a broad range of applications

Development of *WRAP* was motivated by the implementation of a water rights permit system in Texas during the 1970's and 1980's and the creation of a statewide *Water Availability Modeling (WAM) System* during the 1997-2002 to support administration of the water rights system (Texas Natural Resource Conservation Commission 1998; Wurbs 2001). Surface water law in Texas evolved historically over several centuries (Wurbs 1995). Early water rights were granted based on various versions of the riparian doctrine. A prior appropriation system was later adopted and then modified. The Water Rights Adjudication Act of 1967 merged the riparian water rights into the prior appropriation system. The allocation of surface water has now been consolidated into a unified permit system. The water rights adjudication process required to transition to the permit system was initiated in 1967 and was essentially completed by the late 1980's.

Senate Bill 1 enacted by the 75th Texas Legislature in 1997 is a comprehensive water resources management legislative package that addresses a wide range of issues including the need to expand statewide water availability modeling capabilities. The Texas Commission on Environmental Quality (TCEQ), which prior to September 2002 was named the Texas Natural Resources Conservation Commission (TNRCC), its partner agencies, and contractors developed the

Texas *Water Availability Modeling (WAM)* System during the period 1997-2002, pursuant to the 1997 Senate Bill 1, to support regulatory and planning activities. The TCEQ *WAM* System development effort resulted in extensive modifications and many evolving versions of *WRAP*. These expansions and refinements of the model are outlined in Appendix C. A brief description of the development of the Texas *WAM* System is provided a little later in this chapter.

The Fort Worth District (FWD) of the U.S. Army Corps of Engineers (USACE) initiated its Congressionally funded *Texas Water Allocation Assessment Project* in 2000 to investigate opportunities for collaboration between federal activities and the state water resources planning and management efforts instigated by the Texas Legislature's 1997 Senate Bill 1. In conjunction with this federal investigation, the USACE FWD is cosponsoring ongoing efforts since 2001 in expanding and improving *WRAP*.

Early Versions of the WRAP Programs

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

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

The original *TAMUWRAP* was replaced by *WRAP2* and *TABLES*, reflecting significant improvements building on the same fundamental concepts. The computational algorithms were refined, additional capabilities were added, the input data format was changed, and the output format was totally restructured. *WRAP3* is more complex than *WRAP2* and provides expanded capabilities, particularly in regard to simulating multiple-reservoir, multiple-purpose reservoir system operations. Developing the revised *WRAP* involved coding completely new computer programs. Model development and application to the Brazos River Basin are described by Dunn (1993). The *WRAP2*, *WRAP3*, and *TABLES* package is documented by Wurbs and Dunn (1996). Further minor revisions were made in conjunction with a water availability modeling project for the San Jacinto River Basin performed at Texas A&M University for the TNRCC in 1996.

WRAPNET based on network flow programming and *WRAPSALT* incorporating salinity considerations were developed for university research projects and are not considered operational for general application by other users. As mentioned above, the research was sponsored by the TWRI, TWDB, USGS, and TATP. These versions of the model are briefly noted as follows but are not otherwise included in this manual.

WRAPNET was developed in conjunction with a research study to evaluate the advantages and disadvantages of adopting a generic network flow programming algorithm for *WRAP* as compared to model-specific algorithms developed specifically for *WRAP* (Yerramreddy 1993; Yerramreddy and Wurbs 1996). Network flow programming is a special form of linear programming that has been adopted for a number of other similar models. Although network flow programming was demonstrated to be a viable alternative modeling approach, the model-specific algorithms were concluded to be advantageous for the *WRAP* model. *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, WRAP3, or WRAP-SIM*.

Development of *WRAPSALT* was motivated by natural salt pollution in the Southwestern United States. The model has been applied to the Brazos River Basin. *WRAPSALT* is an expanded version of *WRAP3* and *TABLES* with features added for simulating salt concentrations and their impacts on water supply reliabilities. Sequences of monthly salt loads are input along with the naturalized streamflows. Water availability is constrained by both salt concentrations and water quantities (Wurbs et al. 1994; Sanchez-Torres 1994; Wurbs and Sanchez-Torres 1996).

Water Availability Modeling (WAM) System Developed Pursuant to Senate Bill 1

Senate Bill 1, Article VII of the 75th Texas Legislature in 1997 directed the Texas Natural Resource Conservation Commission (TNRCC) to develop water availability models for the 22 river basins of the state, excluding the Rio Grande. Models for six river basins were to be completed by January 2000, and the 16 others completed by January 2002. Subsequent legislation authorized modeling of the Rio Grande Basin. The *Water Availability Modeling (WAM)* project was conducted collaboratively by the TNRCC (as lead agency), Texas Water Development Board (TWDB), Texas Parks and Wildlife Department (TPWD), consulting engineering firms, and university research entities, in coordination with the water management community. Effective September 2002, the TNRCC was renamed the Texas Commission on Environmental Quality (TCEQ). The *WAM System* includes databases and data management systems as well as the *WRAP* simulation model and associated data files for each of the 23 river basins (TNRCC 1998; Sokulsky, Dacus, Bookout, Patek 1998; Wurbs 2001).

During 1997-1998, the TNRCC, TWDB, TPWD, and a team of consulting firms evaluated available river/reservoir system simulation models to select a generalized model to adopt for the water allocation simulation component of the statewide water availability modeling system (TNRCC 1998). Leading models investigated included *MODSIM* developed at Colorado State University, *STATEMOD* developed by the state of Colorado, *MIKE BASIN* developed by the Danish Hydraulic Institute, and others. This study resulted in adoption of *WRAP,* along with development of recommendations for expanding and improving the model.

Consulting engineering firms under contract with the TNRCC during 1998-1999 applied *WRAP* to the initial river basins, which included the Sulphur, Neches, Nueces, San Antonio, and Guadalupe. Work on the Trinity and San Jacinto River Basins and adjoining coastal basins was initiated in 1999. Work on the Brazos River Basin was initiated in early 2000, with the remainder of the original 22 basins following shortly thereafter. Initial modeling of the 22 river basins was completed by 2002. The Rio Grande, the 23rd and last basin, was modeled in 2002-2003. The *WRAP* input data sets and simulation results for each of the individual river basin modeling studies are available from the TCEQ. The TCEQ has provided all permit holders information regarding reliabilities associated with their water rights.

Numerous recommendations for expanding and improving *WRAP* have been made by the agency and consulting firm personnel responsible for the model evaluation study and the river basin modeling studies. The primary TNRCC contractors participating in these efforts included Parsons Engineering Science, R. J. Brandes Company, HDR Engineering, Freese & Nichols, Inc., Espey Padden Consultants, Brown & Root, Inc., Center for Research in Water Resources (CRWR) at the University of Texas, and Texas Water Resources Institute (TWRI) at Texas A&M University. Other consulting engineering firms also assisted as subcontractors.

The Center for Research in Water Resources (CRWR) at the University of Texas, under contract with the TNRCC, developed an *ArcView/ArcInfo* based geographic information system (GIS) for delineating the spatial connectivity of pertinent sites and determining watershed parameters required for distributing naturalized streamflows (Hudgens and Maidment 1999; Figurski and Maidment 2000; Mason and Maidment 2000; Maidment 2002). The watershed parameters are drainage area, curve number (representing soil type and land use), and mean precipitation. The CRWR applied the GIS to the various river basins and provided the resulting information to the consulting firms responsible for modeling each of the river basins.

Methods for developing naturalized streamflows at gaged and ungaged sites were investigated and adapted for *WRAP* under a 1997-1999 contract between the TNRCC and TWRI (Wurbs and Sisson 1999). Capabilities for adjusting streamflows at gaging stations to develop naturalized flows are included in *WRAP-HYD*. Approaches for distributing flows from gaged to ungaged sites were developed and incorporated into *WRAP-HYD* and *WRAP-SIM*.

WRAP has been greatly expanded and improved under a 1998-2003 TNRCC/TCEQ-TWRI cooperative agreement. Continuing development efforts during 2001-2003 are also sponsored by the USACE FWD. *WRAP-SIM* was developed by modifying and expanding *WRAP-3* and has continued to evolve through many more additions and refinements. *TABLES* has been revised to adapt to the new capabilities in *WRAP-SIM*, and various new tables have been added. The new *WRAP-HYD* and *WinWRAP* have been added to the software package. Modifications reflected in various versions of *WRAP* are outlined in Appendix C.

Prior to this *Reference Manual* and accompanying *Users Manual*, *WRAP* was documented by a single combined manual (Wurbs 2001) that had evolved through multiple editions and a supplement (Wurbs 2003) that covered modifications since publication of the July 2001 manual. The present reference and user manuals reflect a restructuring of the manual format, refinements for clarity and utility, and addition of the revisions to the model made since the July 2001 manual.

Work is currently underway to expand *WRAP* to include the following additional new modeling capabilities:

- conditional reliability modeling
- daily or other sub-monthly time step options
- salinity tracking

Conditional reliability modeling (CRM) versions of *WRAP-SIM* and *TABLES* are currently being tested and refined (Salazar 2002; Salazar and Wurbs 2003). The CRM features are not included in the publicly-distributed March 2003 versions of the WRAP software and documentation but will be added soon. The CRM features are designed to develop estimates of the likelihood of meeting diversion, instream flow, hydropower, and storage targets during specified time periods of one month to several months or a year, into the future, given current storage levels and specified premises regarding water management. Reliabilities are conditioned upon initial storage contents. Applications include water management decision-support during actual droughts, developing reservoir operating policies and drought contingency plans, operational planning studies, and analyzing initial impoundment periods for proposed new reservoir projects.

Conditional reliability modeling (CRM) uses the same input data as the conventional *WRAP-SIM*, including the same sequences of naturalized streamflows and evaporation-precipitation rates. CRM is based on dividing the several-decade-long hydrologic sequences into many annual sequences. For example, 1940-2000 hydrologic sequences may be divided into 61 annual 12-month long sequences. A methodology assigns exceedance probabilities to each sequence conditioned on simulated storage. The *WRAP-SIM* computations are automatically repeated with each of the many hydrologic sequences, starting with the same specified initial reservoir storage levels for each of the simulations. Reliabilities and related information are developed from the simulation results. The short-term reliabilities for meeting water right requirements are conditioned upon preceding reservoir storage contents.

Incorporation of sub-monthly time step features is another area of model development currently underway. The modeler will be able to divide each of the 12 months of the year into smaller time steps with a default of daily. *WRAP-SIM* input will optionally include either daily (sub-monthly) naturalized streamflows or flow patterns for distributing monthly flows to daily flows. An adaptation of the Muskingum method will be used for routing. *WRAP-SIM* simulation results will be aggregated to monthly values for use in the existing *TABLES* monthly tables and indices. Additional *TABLES* routines will be developed to organize daily results and develop daily-based frequency relationships and reliability indices. The applicability of the daily time step features in modeling water supply, hydroelectric power generation, environmental instream flow needs, and flood control operations is being investigated.

Natural salt pollution in Texas and neighboring states results in needs for considering salinity in assessing water availability. Previous efforts to incorporate salinity considerations into *WRAP* have been recently reactivated. A new *WRAP* program is being developed for tracking salt concentrations throughout a river/reservoir system for alternative water management/use scenarios. The program will read water quantity data from the *WRAP-SIM* output file along with additional

data regarding salt concentrations of entering naturalized streamflows. The proposed model will then compute concentrations of these water quality constituents in the regulated streamflows and reservoir storage contents throughout the river basin.

CHAPTER 2
OVERVIEW OF THE SIMULATION MODEL

Modeling Capabilities

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

WRAP is designed specifically to facilitate incorporation of a water rights priority system in water availability modeling. Within *WRAP*, water is allocated among users based on specified priorities. The model was motivated by and developed within the framework of the Texas water rights permit system. However, it is applicable to prior appropriation permit systems common in other western states as well. *WRAP* may also be applied in situations in which water is allocated without formal water rights permits or any particular type of water rights system. The model is designed for analyzing river basins that may have hundreds of reservoirs, hundreds of water supply diversions, complex water use requirements, and complex water management practices. However, it is applicable to relatively simple systems as well.

The generalized computer model provides 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. Water management/use may involve reservoir storage, water supply diversions, return flows, environmental instream flow requirements, and hydroelectric power generation. Multiple-reservoir system operations and off-channel storage may be simulated. Flexibility is provided for modeling the various rules specified in water rights permits and/or other institutional arrangements governing water allocation and management.

WRAP basically provides an accounting system for tracking streamflow sequences, subject to specified reservoir storage capacities and diversion, hydropower, 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 premises of (1) a repetition of historical hydrology and (2) the full amounts of all specified water use requirements are met as long as water is available from streamflow and/or specified reservoir storage capacity. However, various other hydrologic and water management scenarios may be simulated as well. Numerous optional features have been incorporated into the generalized model to address complexities in the variety of ways that people manage and use water. The Fortran programs are designed to facilitate adding new features and options as needs arise.

Water Availability Modeling Process

The conventional overall water availability modeling process for a river basin consists of two phases:

1. developing sequences of monthly naturalized streamflows covering the hydrologic period-of-analysis at all pertinent locations

    a) developing sequences of naturalized flows at stream gaging stations *[WRAP-HYD]*

    b) extending record lengths and filling in gaps to develop complete sequences at all selected gages covering the specified period-of-analysis *[Not included in WRAP]*

    c) distributing naturalized flows from gaged to ungaged locations *[HYD or SIM]*

2. simulating the rights/reservoir/river system, given the input sequences of naturalized flows, to determine regulated and unappropriated flows, storage, reliability indices, flow-frequency relationships and related information regarding water supply capabilities

    a) simulating the rights/reservoir/river system *[WRAP-SIM]*

    b) computing water supply reliability and streamflow frequency indices and otherwise organizing/summarizing/displaying simulation results *[TABLES]*

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

WRAP-HYD includes options to assist in adjusting gaged flows to obtain naturalized flows (Phase 1a above). Naturalized flows may be distributed from gaged (or known-flow) locations to ungaged (unknown-flow) locations (Phase 1c) within either *WRAP-HYD* or *WRAP-SIM*. *WRAP* does not include regression methods to extend records or reconstitute missing data (Phase 1b). Readily available spreadsheet and statistical software packages include regression analyses.

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

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

Control Point Representation of Spatial Configuration

The spatial configuration of a river/reservoir/use system is represented in *WRAP* as a set of control points that represent pertinent sites in the river basin. Reservoirs, diversions, return flows, instream flow requirements, streamflows, evaporation rates, and other system features are assigned control points denoting their locations. Control points provide a mechanism to model spatial connectivity. The *CP* input record for each control point includes the identifier of the next control point located immediately downstream. Several computational routines in *WRAP-HYD* and *WRAP-SIM* include algorithms allowing the computations to cascade downstream by control point. Spatial complexity in actual applications may range from a system modeled with a single control point to models with several control points to those with several thousand control points. The number of control points incorporated in the models for each of the 23 river basins in the *Texas WAM System* range from less than 100 to over 3,000.

Naturalized streamflows at each control point are either input to *WRAP-SIM* or computed within the model from flows at other control points. Options are available for distributing naturalized flows from gaged to ungaged control point locations. *WRAP-SIM* computes unregulated flows, unappropriated streamflows, and other quantities for each control point.

Each water right must be assigned a control point. The control point assignment basically means that the right has access to available streamflow at that location. It also allows the effects of the water right on other rights to be properly modeled. Each water right can be assigned a separate control point. Alternatively, rights can be grouped such that the rights assigned to a given control point include all those located along specified stream reaches. Multiple water rights at the same control point all have access, in priority order, to the streamflow available at the control point. Any number of reservoirs can be associated with a single control point, but each control point is limited to one set of reservoir net evaporation-precipitation rates.

Simulation Input

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

Input describing water rights includes control point location, annual diversion amount, instream flow requirements, hydroelectric energy demand, storage capacity, type of water use, and return flow specifications. A set of 12 monthly water use distribution factors is input for each water use type. Diversion, instream flow, and hydropower targets optionally may be specified as a function of reservoir storage or streamflow. Return flows may be specified as a fraction of diversions or as a constant amount, return flow location, and whether the return flows occur the same month as the diversion or the next month. Water right priority numbers may be entered for each individual right on *WR* or *IF* records or for water use type groups on *UC* records. Optionally, water use demands may be met in natural upstream-to-downstream order. Priority numbers often reflect the priority dates specified in the permit for each right. For example, a water right established as of May 1, 1972 is represented by a priority number of 19720501, which is a smaller number than the priority of more junior rights. The model-user can adopt other schemes for assigning relative priorities to fit the particular application. The model provides considerable flexibility for applying ingenuity in combining the available water rights modeling options to simulate a particular water management/use scenario.

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

Simulation Results

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

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

Simulation results are written to the *WRAP-SIM* output file, which is read by *TABLES*. The program *TABLES* computes reliability indices, including volume and period reliabilities, and streamflow and storage frequency relationships and organizes the simulation results as tables of information in various user-specified optional formats.

For each month of a *WRAP-SIM* simulation, output records are written for user-selected water rights (diversion rights and instream flow rights), control points, and reservoir/hydropower projects. These records contain the data listed in Table 2-1. More detailed lists with record formats are provided in the *Users Manual*. Some data are unique to water right, control point, or reservoir/hydropower output records. For example, naturalized, unregulated, and unappropriated flows, and channel losses are associated only with control points. Hydroelectric energy is recorded

only on reservoir/hydropower records. Other data are repeated on two or three of the record types.
For example, reservoir storage and evaporation are written to all three records. If one water right
with one reservoir is located at a control point, reservoir storage will be identical on all three
records. However, the control point records contain the summation of storage contents of all
reservoirs assigned to the control point. Likewise, multiple water rights may be assigned to the
same reservoir. Diversions and shortages on a control point record are the totals for all the diversion
rights assigned to the control point. The diversions and shortages on a water right output record are
associated with a single *WR* input record.

<div align="center">

Table 2-1
Variables in the WRAP-SIM Output File

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Diversion Rights	Instream Flow Rights	Control Points	Reservoir/Hydropower
diversion target	instream flow target	diversion target	energy generated
diversion shortage	flow shortage	diversion shortage	energy shortage
storage volume	storage volume	storage volume	secondary energy
evap-precip volume	evap-precip volume	storage volume	storage volume
available streamflow	available streamflow	evap-precip volume	evap-precip volume
streamflow depletion	streamflow depletion	unappropriated flow	reservoir inflow
reservoir releases	required res release	streamflow depletion	reservoir release
first identifier	reservoir release	naturalized flow	turbine flow
second identifier	res release shortage	regulated flow	identifier
third identifier	identifier	return flow	
		channel loss	
		channel loss credit	
		identifier	

The time series of monthly values of the variables listed in Table 2-1 are read by the
postprocessor *TABLES*, which in turn creates user-specified tables to organize, display, and
summarize the simulation results. Some of the *TABLES* routines simply rearrange and tabulate,
with appropriate table headings, selected data read from the *WRAP-SIM* input or output file. Other
routines include computational algorithms, which may range from simple sums or statistics to more
complex arithmetic operations. A reliability table for water supply diversion or hydroelectric
energy targets includes volume reliabilities and period reliabilities for meeting various percentages
of the target demands. Flow-frequency tables are developed for naturalized flows, unregulated
flows, unappropriated flows, reservoir storage, and instream flow shortages. Reservoir storage may
be also displayed as comparative tables of percentages of capacity and drawdown-duration tables.
TABLES also creates tables organizing and summarizing water rights data read from a *WRAP-SIM*
input file.

<div align="center">

Units of Measure

</div>

Any units may be adopted. However, the set of all input data units and conversion factors
must be computationally consistent. The various flows (volume per month or volume per year)
must have the same volume units as the reservoir storage volume units. Most of the input data are
volumes, areas, or depths, including annual and monthly diversion volumes, volume/month
streamflow rates, reservoir storage volume and surface area, and net evaporation-precipitation

depths. Net evaporation volumes are depths multiplied by reservoir water surface areas. An example of a set of computationally consistent (feet×acre=acre•feet) English units is as follows:

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

An example of a set of computationally consistent metric units is as follows:

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

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

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

Organization of the Simulation Computations

The software package consists of the system simulation model *WRAP-SIM*, hydrology data compilation program *WRAP-HYD*, post-simulation program *TABLES*, and user interface *WinWRAP*. *WRAP-HYD* is a set of optional routines to facilitate developing naturalized streamflow and evaporation-precipitation rate data sets for input to *WRAP-SIM*. *TABLES* is used to compute water supply reliability, streamflow-frequency, and storage-frequency indices and to build tables organizing the simulation results. Tables developed with program *TABLES* may be used directly to display simulation results or imported to other programs such as *Microsoft Excel* for plotting and further data manipulation. *WinWRAP* facilitates executing the programs within Microsoft Windows and using Microsoft programs to edit files. As indicated in Table 2-2, instructions for preparing input files for *WRAP-SIM*, *TABLES*, and *WRAP-HYD* are provided in the *SIM*, *TAB*, and *HYD* sections, respectively, of the *Users Manual (UM)*. The individual programs are also covered in the chapters and appendices of the *Reference Manual (RM)* noted in Table 2-2.

Table 2-2
Organization of Reference Manual (RM) and Users Manual (UM)

	WRAP-SIM	*TABLES*	*WRAP-HYD*
Description of capabilities and methods	RM Ch 2-4	RM Ch 2	RM 3
Detailed instructions for preparing input data	UM SIM	UM TAB	UM HYD
Definition of Fortran subroutines and variables	RM Appd D	RM Appd E	RM Appd F
Examples	RM Appd G	RM Appd G	RM Appd H

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

The *WRAP-SIM* simulation procedure is outlined in Figure 2-1 from a general overview perspective. After first reading a major portion of the input data, the simulation is performed in a set of nested loops. The computations proceed by year and, within each year, by month. Within each month, the water rights are considered in priority order, and the computations are performed for each water right in turn. As explained in Chapter 4, instream flow requirements may require passing through the water rights loop twice in a particular month. Water right output data records, described in the *Users Manual*, are written to the *WRAP-SIM* output file as each right is considered in the priority loop. Control point output is written at the completion of the water rights loop.

For each month of the simulation, *WRAP-SIM* performs the water accounting computations for each water right, in turn, on a priority basis. The computations proceed by month and, within each month, by water right with the most senior water right in the basin being considered first. *WRAP-SIM* computes diversions and diversion shortages associated with each water right. Environmental instream flow requirements are considered. Permitted reservoir storage capacity is filled to the extent allowed by available streamflow. Reservoir net evaporation-precipitation is computed and incorporated in the water balance. Return flows are computed and re-enter the stream at user-specified control points. An accounting is maintained of storage levels in each reservoir and streamflow still available at each control point.

In applying the model, considerable flexibility is provided for specifying water right requirements. The user should always remember the following fundamental features of the computational algorithms when representing water rights requirements in the model.

- The simulation progresses sequentially by month. The following basic features of the model connect a month with the preceding month. The computed end-of-period reservoir storage for a month becomes the given beginning-of-period storage for the next month. An option allows return flows from diversions occurring in a given month to be returned to the stream the next month. Hydropower releases may also be made available at downstream locations optionally the following month. Options limit cumulative annual diversions, withdrawals from storage, and streamflow depletions.

- A water rights priority loop is embedded within the monthly computational loop. In a particular month, the water rights are considered in priority order. Thus, in general, each water right is affected only by more senior rights, with the following exceptions. As noted above, reservoir storage is affected by previous month computations, and the next-month return flow option allows senior rights access to junior return flows. Instream flow requirements are considered in a dual loop within the water rights loop. Thus, junior rights may affect regulated flow constraints on water availability for more senior rights.

1. Program *WRAP-HYD* facilitates developing the *WRAP-SIM* hydrology input files.

2. The *WRAP-SIM* simulation is outlined as follows.

   - Input Data Read and Organized
     - Subroutine *WRAPIN* reads all input except that related to hydrology.
     - Subroutine *WRAPIN* performs various data manipulations.
     - Subroutines *RANKWR* or *NATURAL* rank the water rights in priority order.
     - Subroutine *IACNP* reads and manipulates watershed parameters for flow distribution.

   - Annual Loop (repeated for each year of simulation)   ----------------------------!
     - Hydrology (*IN* and *EV*) records are read by subroutine *INFEVA*.   !
     - Flows are distributed from gaged to ungaged sites by subroutine *FLDIST* !
     - Incremental negative inflow adjustments are developed by *INCREM*.   !
     - Flows for January are adjusted for return flows from prior December.   !

   - Monthly Loop (repeated for each month of simulation) * * * * * * * * * * * *!
     - Net evaporation-precipitation adjustment option.   * !
     - Spills associated with monthly varying storage capacity option.   * !
     - Flow adjustments for constant inflow/outflow option.   * !
     - Available flows are saved for second pass through water rights   * !
         loop for instream flow options.   * !
                                                                                  * !
       - Water Right Loop (repeated for each right in priority order) + + + + * !
       +   (First and second pass through loop for instream flow options)   +* !
       +   - The diversion, instream flow, or hydropower target is set.   +* !
       +   - The amount of water available to right is determined.   +* !
       +   Unappropriated flows are checked by *AVALB*.   +* !
       +   Regulated flows are checked by *AVALB*.   +* !
       +   (Channel losses are considered in the above tasks.)   +* !
       +   - Diversions, reservoir releases, and return flows are made.   +* !
       +   (Includes reservoir water balance with iterative net   +* !
       +   evaporation-precipitation and hydropower computations.)   +* !
       +   - Available streamflow at all control points is adjusted.   +* !
       +   (Channel losses are considered in above.)   +* !
       +   - Water right output records are developed and written.   +* !
       •   + * !
                                                                                  * !
       - Control point and reservoir output records are developed and written. * !
                                                                                  * !
       *!
   ---!

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

Figure 2-1. **Outline of WRAP Simulation**

All of the input data is read at the beginning of a *WRAP-SIM* execution, except naturalized streamflows and reservoir net evaporation-precipitation rates. An optional flow adjustment file may also be read during the simulation. Various manipulations of the water rights input data read at the beginning are performed prior to starting the monthly simulation. This includes a ranking mechanism for identifying the priority order of the water rights based on priority numbers from the input data.

The annual loop begins with reading the streamflow and evaporation data for each of the 12 months of that year and distributing flows from gaged to ungaged control points. The computations are then performed on a monthly basis. The data in the control point and reservoir/hydropower output records listed in Table 2-1 reflect the effects of all the rights and are outputted each month at the completion of the water rights loop.

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

1. First, the amount of streamflow available to the right is determined. 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.

2. Water balance computations are then performed to compute the streamflow depletion, reservoir evaporation, end-of-period storage, return flow, diversion and diversion shortage, and hydroelectric energy generated and shortage. The interrelationships between the variables necessitate an iterative algorithm. For multiple reservoir system operations, the releases and storages for all the system reservoirs are computed.

3. Upon completion of the water right computations, both regulated and unappropriated flows at all pertinent control points are computed through a series of adjustments reflecting the effects of the water right. The streamflow amounts still available at the control point of the water right and at downstream control points are decreased by the streamflow depletion and increased by the return flow and hydropower release.

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

The objective of Example 1 is to illustrate the three computational stages within the water rights loop. Data for the example are presented in Figure 2-2 and Tables 2-3, 2-4, and 2-5. The example focuses on the computations for just one month of a simulation. The spatial configuration of the system is represented by five control points shown in Figure 2-2. Information for each of three water rights is provided in Table 2-3. Water right WR-A includes reservoir storage as well as a diversion. Water rights WR-B and WR-C are run-of-river diversion rights.

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Table 2-3
Water Rights Information for Example 1

</div>

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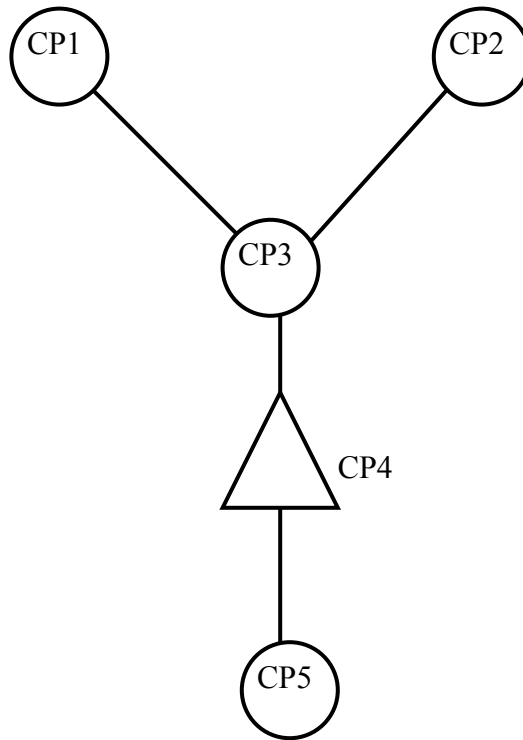
Figure 2-2. **Control Point Schematic for Example 1**

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Table 2-4
Water Rights Simulation Results for Example 1

</div>

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

Table 2-5
Streamflow for the Month at Each Control Point in Example 1

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

A WRAP-SIM simulation consists of allocating available water to water rights in priority order. Available water consists of streamflow during the month and reservoir storage content at the beginning of the month. For this particular month, naturalized streamflow is 100 acre-feet at control point CP5 with lesser amounts at the four other control points located upstream of CP5 as tabulated in column 2 of Table 2-5. The beginning-of-month storage in the WR-A reservoir at CP4 is 195 ac-ft as shown in column 6 of Table 2-3. These naturalized flows and beginning-of-month storage are to be allocated to meet the three diversion requirements, satisfy reservoir net precipitation-evaporation, and refill the reservoir storage to capacity. The water use requirements are met to the extent allowed by available streamflows and beginning-of-month reservoir storage. The water rights are listed in priority order in Table 2-3 with their priorities being tabulated in column 3. The computations begin with WR-A, the most senior right. Water rights WR-B and WR-C are then considered in order of priority.

Stage 1 consists of determining the amount of water available this month for water right WR-A at control point CP4. The amount of streamflow available is the lesser of the naturalized flow at CP4 (80 ac-ft) and all downstream control points (100 ac-ft at CP5). Thus, for WR-A, the available streamflow this month is 80 ac-ft as shown in column 3 of Table 2-4. Beginning-of-month storage of 195 ac-ft is also available.

Stage 2 for WR-A consists of performing water budget computations to determine the extent to which the water right requirements will be met. As indicated by Table 2-3, WR-A includes a permitted diversion amount of 15 ac-ft for this month. The beginning-of-month reservoir storage of 195 ac-ft is 5 ac-ft below the storage capacity of 200 ac-ft. As discussed later, the volume of reservoir net evaporation-precipitation is computed by averaging the water surface areas at the beginning and end of the month, determined as a function of storage, and multiplying by a net evaporation-precipitation depth provided in the input data. An iterative algorithm is required to compute the net evaporation-precipitation volume and end-of-month storage since these two variables are both dependent on each other. For purposes of this example, if the reservoir is full at the end of the month, we will assume that computations, not shown, yield a net evaporation-precipitation volume of 20 ac-ft. Thus, requirements for water right WR-A are 20 ac-ft for net evaporation-precipitation (based on the reservoir being completely refilled), 5 ac-ft for refilling storage, and 15 ac-ft for the water supply diversion, for a total of 40 ac-ft. These requirements are all met by the available streamflow of 80 ac-ft.

Stage 3 consists of adjusting the streamflows at CP4 and CP5 to reflect the streamflow depletion of 40 ac-ft at CP4. Prior to considering WR-A, the available (yet unappropriated) streamflows at CP4 and CP5 are the naturalized flows of 80 and 100 ac-ft. Reducing the flows at CP4 and CP5 by the WR-A streamflow depletion of 40 ac-ft results in the intermediate computational control point (CP) flows shown in column 3 of Table 2-5. The now available (still unappropriated) streamflows at each control point are tabulated in column 4 of Table 2-5.

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

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

The computed water right diversions, shortage, and end-of-month storage are tabulated in Table 2-4. The final regulated flows and unappropriated flows at each control point are shown in columns 7 and 8 of Table 2-5.

Water Accounting Procedures

Thus, as illustrated by the preceding example, for a given month, as the computations are performed for each water right in priority order, an accounting is maintained of the amount of regulated and unappropriated streamflow remaining at each control point location. Streamflow is treated as total flows rather than incremental or local flows. An intermediate computational streamflow at each control point begins as the naturalized flow and is adjusted to reflect the effects of each water right located at the control point of the right or upstream. 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 this flow at each of the individual downstream control points and 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 streamflow still remaining at that control point and each individual downstream control point are decreased to reflect the streamflow depletion. The streamflow at the control point location at which the diversion return flow is returned as well as at all downstream control points is increased to reflect the return flow. Flows are increased by return flows, hydropower releases, and reservoir releases. Channel losses may be included in these computations.

The streamflow depletion for a water right with reservoir storage will include the net volume of evaporation less precipitation. The streamflow depletion may also include water taken to refill previously drawn-down reservoir storage. Conversely, water use requirements may be met by withdrawals from reservoir storage. The water accounting computations for a

storage right include computation of reservoir net evaporation-precipitation volume. An input net evaporation minus precipitation depth is applied to the average water surface area, which is determined as a function of average storage during the period, determined by averaging the storage at the beginning and end of the period. An iterative algorithm is used since evaporation volume depends on end-of-period storage, which is a function of evaporation. Likewise, an iterative algorithm is used to determine hydroelectric power releases, that depend on head, which is a function of end-of-month storage.

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

$$S_{T-1} + D_{SF} = W_{WS} + R + E + S_T \qquad (2\text{-}1)$$

where:

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

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

Any number of water rights may include storage capacity in the same reservoir. Each right allows storage to be refilled to a specified cumulative storage capacity with a specified priority. The storage capacity associated with refilling by junior rights must equal or exceed refill capacities associated with more senior rights. All rights associated with a reservoir have access to all water in their active pools for use in meeting diversion, instream flow, and hydropower requirements. An inactive pool capacity may also be specified for each right, from which the right can not take water. Otherwise, reservoir storage is not divided into separate pools associated with each right.

In the computations, the end-of-period storage depends upon all the rights associated with the reservoir. For a senior water right, the beginning-of-period storage can be impacted by the computations for the previous month for junior rights at the same reservoir. For a hydropower right, the actual beginning-of-period and end-of-period storages are used in the computations, even if the capacity associated with the right is exceeded due to other rights. For a diversion right, the beginning-of-period and end-of-period storages used in the computations for that particular right are limited to not exceed the storage capacity associated with the right. Thus, the storage capacity for a junior right at a reservoir must be equal to or greater than the storage capacity of any senior right at the reservoir.

Constructing a Model with WRAP

Building a *WRAP* model for a particular river basin consists of developing input information in the format of records that are stored in files. Required input files must be developed prior to running the programs. *WRAP* does not include built-in editing capabilities. Model-users create and revise various input files in the format outlined in this manual using their choice of editor, spreadsheet program, and/or other software. *Microsoft Excel*, *Word*, *WordPad*, and the *MS-DOS Editor* are popular programs that may be used to create, edit, and manipulate text files used in *WRAP*. Certain other input files are created by the *WRAP* programs. As previously discussed, *WRAP-HYD* output files become *WRAP-SIM* input files, and *WRAP-SIM* output files become *TABLES* input files.

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

The size of a *WRAP-SIM* model may vary from a few input records to many thousand. The smallest possible *WRAP-SIM* model would contain one each of the *T1*, *JD*, *CP*, *WR*, *IN*, and *ED* records described in the *Users Manual*. Actual applications may involve data sets with less than a hundred records, but many typical applications involve several thousand records. A *WRAP-SIM* model with 500 control points, a 50-year period-of-analysis, naturalized streamflows at 20 gaged control points, and evaporation-precipitation rates at 20 control points includes: 500 *CP* records; 1,000 *IN* records (50 for each of 20 control points); 1,000 *EV* records; 480 *FD* and *WP* records for distributing flows from 20 gaged to 480 ungaged control points; and many hundreds of water rights *WR* records and other records of various types.

WRAP applications may be simple. A *WRAP* input data set may involve only a few types of records using relatively simple options. On the other hand, applications may be quite complex. River basin hydrology, water control facilities, water use requirements, institutional water allocation procedures, and management policies/practices for major river basins are complicated. Many varied options are incorporated in the generalized *WRAP* modeling system in order to provide flexible capabilities for analyzing a comprehensive range of river basin management situations. Complexities in applying *WRAP* are related primarily to (1) the numerous optional features available for modeling various complexities of water management and (2) the need to compile and manage large amounts of data. Ingenuity is required to combine the appropriate *WRAP* options to model complex systems of rivers, reservoirs, and water rights. Significant time, effort, and expertise are required to compile the voluminous input data, perform a simulation study, and analyze and interpret results.

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

The following Example 2 is a simple hypothetical *WRAP-SIM* application presented to introduce fundamental features of the model. The example combines title *T1,T2*, comment **, job control data *JD*, use coefficient *UC*, control point *CP*, instream flow *IF*, water right *WR*, water right reservoir storage *WS*, storage volume *SV* versus surface area *SA*, end of data *ED*, inflow *IN*, and evaporation *EV* records, all stored in a DAT file with the filename exam1.dat. This represents only 13 of the 43 record types outlined in the *Users Manual*, and many of the fields of these records are left blank, meaning various optional features are not used. However, the fundamental record types introduced by this simple example may be the only records needed to construct large real-world models. A large river basin with many pertinent sites simply means more *CP* records. A greater number of reservoirs and water rights translate to more *IF*, *WR*, *WS*, *SV*, and *SA* records. A several decade long hydrologic period-of-analysis requires many more *IN* and *EV* records. As the complexity of the river basin management system increases and/or various other modeling situations are encountered, the various optional features described in subsequent chapters are incorporated into the modeling application. Most water management situations may be modeled using simple basic features of *WRAP*. However, optional capabilities are provided to model a comprehensive range of complicated water rights and water management scenarios.

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

A system consisting of a reservoir, two water supply diversions, and an environmental instream flow requirement, is modeled using a three year hydrologic period-of-analysis. The *WRAP-SIM* input file (filename exam1.dat) and the first part of the output file (exam1.out) are reproduced as Tables 2-6 and 2-8. To save space, only the first eleven months of the simulation results are included in Table 2-8. *TABLES* input and output files (filenames tab1.dat and tab1.out) are shown in Tables 2-7 and 2-9. Information entered in each field of each *WRAP-SIM* and *TABLES* input record is explained in Sections *SIM* and *TAB*, respectively of the *Users Manual*. The data in the *WRAP-SIM* output file are defined in Tables 13, 14, and 15 of the *Users Manual*. Several tables created by *TABLES* (filename tab1.out) from the *WRAP-SIM* output file (exam1.out) summarizing the simulation results are shown in Table 2-9.

As shown in Figure 2-3, the spatial configuration is represented by two control points, CP1 and CP2. Of the three water rights, the environmental instream flow requirement of 1,000 acre-feet/month at CP2 has the highest priority (priority number 1). The 38,000 acre-feet/year run-of-river irrigation diversion right at CP2 is the most junior (priority number 3). The third right consists of a municipal diversion of 96,000 ac-ft/year from RES-A and refilling the storage capacity of 110,000 acre-feet. Annual instream flow and diversion requirements are distributed over the 12

months of the year using the use coefficients entered on *UC* records, except for the instream flow right which uses the default constant uniform distribution. The naturalized streamflows on the *IN* records are in units of acre-feet/month. The net evaporation-precipitation rates on the *EV* records are in inches. A multiplier factor of 0.08333 is included on the *CP* record for CP1 to convert to feet. A storage (acre-feet) versus water surface area (acres) relationship for reservoir Res-A is defined by *SV/SA* records.
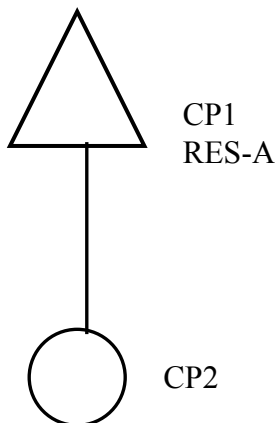
Figure 2-3. **Control Point Schematic for Example 2**

The system is simulated with *WRAP-SIM*, and the simulation results are organized using program *TABLES*. The *TABLES* input file (filename tab1.dat) shown in Table 2-7 and *WRAP-SIM* output file (exam1.out) shown partially in Table 2-8 are read by *TABLES* to create file tab2.out, which is reproduced as Table 2-9. The several sample tables shown in Table 2-9 illustrate some of the types and variations of tables that may be created by *TABLES* to organize and summarize simulation results.

Table 2-9 begins with two annual summary tables for control points CP1 and CP2. *TABLES* provides options to develop monthly and/or annual summary tables for control points, reservoirs, water rights, selected groups of water rights, or the entire river basin. Quantities from the summary tables are related by volume balances. For example, for simulation year 1955 at control point CP1:

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

276,920 ac-ft/yr + 0 = (94,677 - 55,772) + 96,000 + 19,479 + 122,536 ac-ft/yr

Streamflow depletions are:

streamflow depletion = diversion + evaporation + storage refilling

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

CP2 1955 streamflow depletion = diversion = 38,000 ac-ft/yr

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

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

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

A reliability summary table is also included in Table 2-9. This type of table may be developed for diversion or hydropower requirements for individual rights, groups of rights, or all rights at control points or reservoirs. The 96,000 ac-ft/yr diversion target at CP1 has no shortages and thus period and volume reliabilities of 100.0%. The monthly diversion requirements for the 38,000 ac-ft/yr diversion at CP2 were met during 16 months of the 24-months for which permitted targets were non-zero, with shortages occurring in the other eight months. The period and volume reliabilities shown in Table 2-9 are computed as:

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

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

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

The first flow-frequency table in Table 2-9 (bottom of page 32) indicates that regulated monthly streamflows at CP2 vary from 1,000 ac-ft to 80,526 ac-ft, with a mean of 7,650 ac-ft. The regulated flow equals or exceeds 2,168 ac-ft during 75% of the 36 months. The second flow-frequency table is in an alternate format in which exceedance frequencies are determined for user-specified flow amounts. Frequency tables may be developed for naturalized, regulated, and unappropriated streamflows, reservoir storage, and instream flow shortage.

The last six tables in Table 2-9 on are illustrative of *TABLES* tables of naturalized, regulated, and unappropriated flows; streamflow depletions; diversions, diversion or instream flow shortages; channel losses; or reservoir storage for either control points, reservoirs, water rights, or water right groups. The data may be tabulated as annual rows with monthly columns and alternatively in a columnar format to facilitate manipulation and plotting in a spreadsheet program such as *Microsoft Excel*.

Table 2-6
WRAP-SIM Input File for Example 2

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

Table 2-7
TABLES Input File for Example 2

```
COMM    Example 2 - TABLES Input File Tab2.DAT
2SCP
2REL
2FRE    2
2FRQ    2    4      CP2    1000     2000     5000    10000
2STO    1    1    1    0    1      CP1
2NAT    1    1    1    0    1      CP2
2REG    1    1    1    0    1      CP2
2UNA    1    1    1    0    1      CP2
2IFS    0    1    1    1    1    Instream Flow
2DIV    1    1    0    1    1Irrigation Right
ENDF
```

Table 2-8
First Portion of WRAP-SIM Output File for Example 2

```
Program WRAP-SIM (October 2000 Version) Output File
 Example 2 - WRAP-SIM Input File Exam1.DAT
 Example 2 from Chapter 2 of the Reference Manual

   1954    3    2    3    0
IF   1     0.0     0.0      0.0      0.0      0.0      0.0      0.0  Instream Flow  1000.0     0.0
1954 1     0.0  5760.0   1853.7 110000.0   7613.7  10200.0      0.0 Municipal Right
1954 1     0.0     0.0      0.0      0.0      0.0   6390.3      0.0Irrigation Right
   CP1     0.0  5760.0   1853.7 110000.0   7613.7   2586.3      0.0  10200.0   2586.3    0.0    0.0
   CP2     0.0     0.0      0.0      0.0      0.0   6390.3   2304.0  12700.0   7390.3    0.0    0.0
IF   2     0.0     0.0      0.0      0.0      0.0   6390.3      0.0  Instream Flow  1000.0     0.0
1954 2     0.0  5760.0   1940.0 108840.0   6540.0   6540.0      0.0 Municipal Right
1954 2     0.0     0.0      0.0      0.0      0.0   2424.0      0.0Irrigation Right
   CP1     0.0  5760.0   1940.0 108840.0   6540.0      0.0      0.0   6540.0      0.0    0.0    0.0
   CP2     0.0     0.0      0.0      0.0      0.0   2424.0   2304.0   7660.0   3424.0    0.0    0.0
IF   3     0.0     0.0      0.0      0.0      0.0   2424.0      0.0  Instream Flow  1000.0     0.0
1954 3     0.0  6720.0   1867.5 103962.5   3710.0   3710.0      0.0 Municipal Right
1954 3     0.0  1520.0      0.0      0.0   1520.0   2738.0      0.0Irrigation Right
   CP1     0.0  6720.0   1867.5 103962.5   3710.0      0.0      0.0   3710.0      0.0    0.0    0.0
   CP2     0.0  1520.0      0.0      0.0   1520.0   1218.0   2688.0   4760.0   2218.0    0.0    0.0
IF   4     0.0     0.0      0.0      0.0      0.0   1218.0      0.0  Instream Flow  1000.0     0.0
1954 4     0.0  6720.0   1749.5 102843.0   7350.0   7350.0      0.0 Municipal Right
1954 4  1032.0  4560.0      0.0      0.0   3528.0   3528.0      0.0Irrigation Right
   CP1     0.0  6720.0   1749.5 102843.0   7350.0      0.0      0.0   7350.0      0.0    0.0    0.0
   CP2  1032.0  4560.0      0.0      0.0   3528.0      0.0   2688.0   9190.0   1000.0    0.0    0.0
IF   5     0.0     0.0      0.0      0.0      0.0      0.0      0.0  Instream Flow  1000.0     0.0
1954 5     0.0  7680.0   1989.4 108273.6  15100.0  15100.0      0.0 Municipal Right
1954 5     0.0  7220.0      0.0      0.0   7220.0   8372.0      0.0Irrigation Right
   CP1     0.0  7680.0   1989.4 108273.6  15100.0      0.0      0.0  15100.0      0.0    0.0    0.0
   CP2     0.0  7220.0      0.0      0.0   7220.0   1152.0   3072.0  21400.0   2152.0    0.0    0.0
IF   6     0.0     0.0      0.0      0.0      0.0   1152.0      0.0  Instream Flow  1000.0     0.0
1954 6     0.0  9600.0   2047.2  96756.5    130.0    130.0      0.0 Municipal Right
1954 6  4520.0  8360.0      0.0      0.0   3840.0   3840.0      0.0Irrigation Right
   CP1     0.0  9600.0   2047.2  96756.5    130.0      0.0      0.0    904.0    774.0    0.0    0.0
   CP2  4520.0  8360.0      0.0      0.0   3840.0      0.0   3840.0   1130.0   1000.0    0.0    0.0
IF   7     0.0     0.0      0.0      0.0      0.0      0.0      0.0  Instream Flow  1000.0     0.0
1954 7     0.0 12480.0   1788.0  82488.5      0.0      0.0      0.0 Municipal Right
1954 7  4223.0  8360.0      0.0      0.0   4137.0   4137.0      0.0Irrigation Right
   CP1     0.0 12480.0   1788.0  82488.5      0.0      0.0      0.0    112.0    112.0    0.0    0.0
   CP2  4223.0  8360.0      0.0      0.0   4137.0      0.0   4992.0    145.0   1000.0    0.0    0.0
IF   8     0.0     0.0      0.0      0.0      0.0      0.0      0.0  Instream Flow  1000.0     0.0
1954 8     0.0 11520.0   1443.6  69524.9      0.0      0.0      0.0 Municipal Right
1954 8  1645.0  5700.0      0.0      0.0   4055.0   4055.0      0.0Irrigation Right
   CP1     0.0 11520.0   1443.6  69524.9      0.0      0.0      0.0    328.0    328.0    0.0    0.0
   CP2  1645.0  5700.0      0.0      0.0   4055.0      0.0   4608.0    447.0   1000.0    0.0    0.0
IF   9     0.0     0.0      0.0      0.0      0.0      0.0      0.0  Instream Flow  1000.0     0.0
1954 9     0.0  8640.0   1217.8  59887.0    220.0    220.0      0.0 Municipal Right
1954 9     0.0  1900.0      0.0      0.0   1900.0   3456.0      0.0Irrigation Right
   CP1     0.0  8640.0   1217.8  59887.0    220.0    752.0      0.0    972.0    752.0    0.0    0.0
   CP2     0.0  1900.0      0.0      0.0   1900.0   1556.0   3456.0   1220.0   2556.0    0.0    0.0
IF  10     0.0     0.0      0.0      0.0      0.0   1556.0      0.0  Instream Flow  1000.0     0.0
195410     0.0  7680.0   1051.2  53465.8   2310.0   2310.0      0.0 Municipal Right
195410     0.0   380.0      0.0      0.0    380.0   3072.0      0.0Irrigation Right
   CP1     0.0  7680.0   1051.2  53465.8   2310.0    340.0      0.0   2650.0    340.0    0.0    0.0
   CP2     0.0   380.0      0.0      0.0    380.0   2692.0   3072.0   3310.0   3692.0    0.0    0.0
IF  11     0.0     0.0      0.0      0.0      0.0   2692.0      0.0  Instream Flow  1000.0     0.0
195411     0.0  7680.0   1092.6  61993.2  17300.0  17300.0      0.0 Municipal Right
195411     0.0     0.0      0.0      0.0      0.0   6572.0      0.0Irrigation Right
   CP1     0.0  7680.0   1092.6  61993.2  17300.0      0.0      0.0  17300.0      0.0    0.0    0.0
   CP2     0.0     0.0      0.0      0.0      0.0   6572.0   3072.0  21800.0   7572.0    0.0    0.0
IF  12     0.0     0.0      0.0      0.0      0.0   6572.0      0.0  Instream Flow  1000.0     0.0
```

Table 2-9
TABLES Output File for Example 2

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP1

YEAR	NATURALIZED STREAMFLOW (ACRE-FEET)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (ACRE-FEET)	UNAPPROPRIATED FLOW (ACRE-FEET)	EOP STORAGE (AC-FT)	EVAPORATION (ACRE-FEET)	REGULATED STREAMFLOW (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1954	66456.0	0.0	60893.7	4348.3	55772.6	19121.2	5562.3	96000.0	0.0
1955	276920.0	0.0	154383.7	122468.3	94677.4	19478.9	122536.3	96000.0	0.0
1956	113800.0	0.0	103122.5	10477.5	83105.5	18694.5	10677.5	96000.0	0.0
MEAN	152392.0	0.0	106133.3	45764.7	77851.8	19098.2	46258.7	96000.0	0.0

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP2

YEAR	NATURALIZED STREAMFLOW (ACRE-FEET)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (ACRE-FEET)	UNAPPROPRIATED FLOW (ACRE-FEET)	EOP STORAGE (AC-FT)	EVAPORATION (ACRE-FEET)	REGULATED STREAMFLOW (AC-FT)	ACTUAL DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1954	85382.0	38400.0	26580.0	24308.3	0.0	0.0	36308.3	26580.0	11420.0
1955	345380.0	38400.0	38000.0	179396.3	0.0	0.0	191396.3	38000.0	0.0
1956	141210.0	38400.0	28788.0	35699.5	0.0	0.0	47699.5	28788.0	9212.0
MEAN	190657.3	38400.0	31122.7	79801.4	0.0	0.0	91801.4	31122.7	6877.3

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

NAME	PERMITTED DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	++++++++ PERCENTAGE OF MONTHS ++++++++ WITH DIVERSIONS EQUALING OR EXCEEDING 100%	95%	90%	75%	50%	25%	>0%	———— PERCENTAGE OF YEARS ———— PERCENTAGE OF PERMITTED DIVERSION AMOUNT 100%	98%	95%	90%	75%	50%	>0%
CP1	96000.0	0.0	100.00	100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CP2	38000.0	6877.3	66.67	81.90	66.7	66.7	66.7	75.0	91.7	100.0	100.0	33.3	33.3	33.3	33.3	66.7	100.0	100.0
Total	134000.0	6877.3		94.87														

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

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

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS FOR CONTROL POINT CP2

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

_____

Table 2-9 (Continued)
TABLES Output File for Example 2

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

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

NATURALIZED STREAMFLOWS (AC-FT) AT CONTROL POINT CP2

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

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP2

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

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP2

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

DIVERSIONS (AC-FT) FOR WATER RIGHT Irrigation Right

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1954	0.0	0.0	1520.0	3528.0	7220.0	3840.0	4137.0	4055.0	1900.0	380.0	0.0	0.0	26580.0
1955	0.0	0.0	1520.0	4560.0	7220.0	8360.0	8360.0	5700.0	1900.0	380.0	0.0	0.0	38000.0
1956	0.0	0.0	1520.0	2688.0	7220.0	4370.0	6062.0	4648.0	1900.0	380.0	0.0	0.0	28788.0
MEAN	0.0	0.0	1520.0	3592.0	7220.0	5523.3	6186.3	4801.0	1900.0	380.0	0.0	0.0	31122.7

Table 2-9 (Continued)
TABLES Output File for Example 2

		STO CP1	NAT CP2	REG CP2	UNA CP2	IFS Instrea	DIV Irrigati
1954	1	110000.0	12700.0	7390.3	6390.3	0.0	0.0
1954	2	108840.0	7660.0	3424.0	2424.0	0.0	0.0
1954	3	103962.5	4760.0	2218.0	1218.0	0.0	1520.0
1954	4	102843.0	9190.0	1000.0	0.0	0.0	3528.0
1954	5	108273.6	21400.0	2152.0	1152.0	0.0	7220.0
1954	6	96756.5	1130.0	1000.0	0.0	0.0	3840.0
1954	7	82488.5	145.0	1000.0	0.0	0.0	4137.0
1954	8	69524.9	447.0	1000.0	0.0	0.0	4055.0
1954	9	59887.0	1220.0	2556.0	1556.0	0.0	1900.0
1954	10	53465.8	3310.0	3692.0	2692.0	0.0	380.0
1954	11	61993.2	21800.0	7572.0	6572.0	0.0	0.0
1954	12	55772.6	1620.0	3304.0	2304.0	0.0	0.0
1955	1	52234.1	4160.0	3304.0	2304.0	0.0	0.0
1955	2	48331.5	3780.0	3304.0	2304.0	0.0	0.0
1955	3	53556.7	15800.0	4068.0	3068.0	0.0	1520.0
1955	4	87992.6	51600.0	7428.0	6428.0	0.0	4560.0
1955	5	110000.0	78000.0	42365.2	41365.2	0.0	7220.0
1955	6	110000.0	96800.0	80525.7	79525.7	0.0	8360.0
1955	7	110000.0	21200.0	3147.6	2147.6	0.0	8360.0
1955	8	110000.0	26500.0	11783.8	10783.8	0.0	5700.0
1955	9	110000.0	31400.0	22312.0	21312.0	0.0	1900.0
1955	10	109284.4	11900.0	5782.0	4782.0	0.0	380.0
1955	11	100700.8	1930.0	4072.0	3072.0	0.0	0.0
1955	12	94677.4	2310.0	3304.0	2304.0	0.0	0.0
1956	1	90502.6	4090.0	3304.0	2304.0	0.0	0.0
1956	2	92197.9	11200.0	4534.0	3534.0	0.0	0.0
1956	3	85101.3	2140.0	2168.0	1168.0	0.0	1520.0
1956	4	79235.4	3210.0	1000.0	0.0	0.0	2688.0
1956	5	110000.0	59300.0	14969.5	13969.5	0.0	7220.0
1956	6	104003.3	7160.0	1000.0	0.0	0.0	4370.0
1956	7	97602.4	10060.0	1000.0	0.0	0.0	6062.0
1956	8	88227.5	4950.0	1000.0	0.0	0.0	4648.0
1956	9	78452.0	1380.0	2556.0	1556.0	0.0	1900.0
1956	10	70866.9	2320.0	3692.0	2692.0	0.0	380.0
1956	11	75549.8	17100.0	6472.0	5472.0	0.0	0.0
1956	12	83105.5	18300.0	6004.0	5004.0	0.0	0.0

Chapter 2 Overview

Measures of Water Availability and Reliability

The purpose of a *WRAP-SIM* simulation is to assess capabilities for satisfying water supply, hydropower, instream flow, and reservoir storage needs. The future is of concern, rather than the past. However, since future hydrology is unknown, historical streamflows and reservoir evaporation-precipitation rates are adopted as being representative of the hydrologic characteristics of a river basin that can be expected to continue into the future. Thus, for most typical applications, *WRAP-SIM* simulates capabilities for meeting specified water management and use requirements during an assumed hypothetical repetition of historical hydrology, represented by sequences of monthly naturalized streamflows and reservoir net evaporation-precipitation rates covering a selected hydrologic period-of-analysis. Various approaches may be adopted in using *WRAP-SIM* to develop an improved understanding of a river basin management system and to support decision-making processes. The results of a conventional *WRAP-SIM* simulation are typically viewed from the perspectives of:

- frequency, probability, percent-of-time, or *reliability of meeting* water supply, instream flow, hydropower, and/or reservoir storage requirements

- frequency, probability, percent-of-time, or *risk of failing to meet* water supply, instream flow, hydropower, and/or reservoir storage requirements

WRAP-SIM simulation results include hydrologic period-of-analysis sequences of monthly values for the variables listed in Table 2-1. A majority of the variables associated with water rights can be summed within *WRAP-SIM* by control point or reservoir. *TABLES* allows simulation results associated with water rights to be aggregated by specified groups of rights. The computer program *TABLES* reads *WRAP-SIM* input and output files, computes reliability indices and frequency relationships, and creates tables organizing and summarizing the simulation results.

Simulation results are used in a variety of ways to develop an understanding of the river basin system. Alternative model runs demonstrate the effects of alternative water use scenarios and management strategies. Simulation results may be organized in various formats including: the entire time sequences of monthly values of various variables; annual summaries; period-of-analysis means; monthly, annual, or period-of-analysis water budgets; reliability indices; and frequency relationships. These forms of information may all be useful in analyzing, interpreting, and applying the results of a simulation study to support decision-making processes.

Concise measures of water availability/reliability are useful in analyzing and displaying simulation results. *TABLES* options include the following frequency statistics for concisely summarizing *WRAP-SIM* results: (1) period and volume reliabilities for water supply diversion and hydroelectric energy generation targets [2REL record] and (2) flow-frequency and storage-frequency relationships [2FREQ and 2FRQ records], and (3) reservoir drawdown-frequency tables [2PER record]. These records are described in the *TAB* Section of the *Users Manual*.

Period and Volume Reliability

A reliability summary is specified in *TABLES* with a *2REL* record as illustrated by Table 2-9. This table may be created for either water supply diversion or hydroelectric energy generation targets for individual water rights, the aggregation of all rights associated with

individual reservoirs or control points, groups of selected rights, or the aggregation of all rights in the model.

TABLES computes period and volume reliabilities. Period reliability is based on counting the number of periods of the simulation during which the specified demand target is, and is not, met without regard to shortage magnitude. Volume reliability reflects the shortage magnitude.

Period reliability is the percentage of the months in the simulation for which a specified demand target is fully met without shortage. Period reliability R_P is computed by *TABLES* from the results of a *WRAP-SIM* simulation as:

$$R_P \quad = \quad \frac{n}{N}(100\%)$$
(2-2)

where *n* denotes the number of months during the simulation for which the demand is fully supplied, and *N* is the total number of months considered. The *2REL* record allows N and n to be defined optionally either considering all months or only months with non-zero demand. The default is for *N* to be defined as the total number of months in the simulation for which the target demand is not zero, and *n* is the number of these months for which the demand is fully met. Optionally, *N* is defined as the total number of months in the simulation, and (*N-n*) is the number of months with non-zero shortages.

Thus, R_P is an expression of the percentage of time that the demand can be met. Equivalently, R_P represents the likelihood or probability of the demand being met in any randomly selected month. Reliability R_P is the complement ($R_P=1-F$) of the risk of failure *F* that the target will not be met.

A *TABLES* reliability summary also includes tabulations of period reliabilities expressed both as the percentage of months and the percentage of years during the simulation during which diversions (or energy produced) equaled or exceeded specified magnitudes expressed as a percentage of the target demand. For example, the table shows the percentage of months in the simulation for which the computed diversion equals or exceeds 75% of the monthly diversion target. It also shows the percentage of years for which the total diversions during the year equal or exceed 75% of the annual permitted amount. The table also shows the percentage of months for which the demand is fully 100% met, which is the period reliability defined by Equation 2-2.

Volume reliability is the percentage of the total demand that is actually supplied. For water supply, the demand is a volume. For hydropower, the demand is energy generated. Volume reliability R_V is the ratio of volume (energy) supplied to the volume (energy) demanded.

$$R_V \quad = \quad \frac{v}{V}(100\%)$$
(2-3)

or, equivalently, the ratio of the mean actual diversion rate to mean target diversion rate.

The firm (safe or dependable) yield associated with a particular diversion or hydropower production demand is defined as the maximum annual demand that can be met with a period and volume reliability of 100.0 percent. Firm yields may be determined by iteratively adjusting a

target amount and rerunning *WRAP-SIM* until the value meeting the definition of firm yield is found. The *FY* record activates a WRAP-SIM option that automates this procedure.

The reliabilities computed by *TABLES* using Equations 2-2 and 2-3 must be interpreted in the context of the targets selected for inclusion in the *WRAP-SIM* simulation results output file. *WRAP-SIM* includes options for specifying diversion and hydroelectric energy targets as a function of reservoir storage. Diversion targets may also be defined as a function of streamflow, storage, and/or other parameters. An option activated by the *SO* record allows specification of which original, intermediate, or final target developed during the target building process is written to the *WRAP-SIM* output file. The default is to write the original target amount from the *WR/UC* records to the output file. *TABLES* reads whichever target amount and shortage that is written in the *WRAP-SIM* output file and computes the water supply diversion or energy generated as the target less the shortage. A *2RET* record allows specification of the target to be adopted for volume reliability computations.

Flow-Frequency and Storage-Frequency Relationships

Frequency tables created with *TABLES 2FRE* and *2FRQ* records are also included in Table 2-9. These tables may be developed for naturalized flow, regulated flow, unappropriated flow, and reservoir storage for specified control points and instream flow shortages and reservoir storage for specified water rights. Exceedance frequency is defined as:

$$\text{Frequency} \quad = \quad \frac{n}{N}(100\%) \tag{2-4}$$

where *n* is the number of months during the simulation that a particular flow or storage amount is equaled or exceeded, and *N* is the total number of months in the simulation.   Thus, the exceedance frequency is an expression of the percentage of time that particular flow or storage amounts can be expected to occur.   Equivalently, the exceedance frequency represents the likelihood or probability of a certain amount of water being available in any randomly selected month.

The *2FRE* table includes the mean and standard deviation, minimum and maximum, and the flow or storage amounts that are equaled or exceeded specified percentages of the time. For the specified frequencies shown in 2-9, *TABLES* sorts/searches the flow or storage data from the *WRAP-SIM* simulation results to find a value that is equaled or exceeded during the specified percentage of the months of the simulation. If a single monthly flow value does not precisely match that frequency, linear interpolation is applied to the two flow values that bracket the specified frequency.

The *2FRQ* table also develops a flow-frequency, storage-frequency, or instream flow shortage-frequency relationship.   However, the model-user enters specified flow or storage values of interest. *TABLES* simply counts the number of months for which a specified amount was equaled or exceeded and applies Equation 2-4 to assign a frequency.

Reservoir storage frequency tables based on Equation 2-4 may be developed with *TABLES* using the *2FRE* or *2FRQ* records for either water rights or control points. The *2PER* record provides an alternative format for this type of information. The *2PER* record results in

two tables for specified reservoirs: (1) tabulations of storage contents as a percentage of storage capacity and (2) drawdown-duration relationships. These tables are illustrated by Example 4 presented in Appendix G. The *2PER* tables are the last two tables in the *TABLES* output file for Example 4.

The first table is a tabulation of end-of-month storage content expressed as a percentage of the storage capacity of a user-specified zone. The storage content as a percentage is

$$\text{percentage of storage} = \frac{S - C_2}{C_1 - C_2}(100\%) \qquad (2\text{-}5)$$

where C_1 and C_2 are the user-specified total storage capacity below the water surface (pool) elevations defining the top and bottom of the storage zone being considered. Typically, C_1 will be the total conservation storage capacity of the reservoir, and C_2 will be entered as zero. C_1 may be the total conservation capacity, and C_2 the inactive storage capacity. However, the active pool zones defined by Figure 4-1 or other zones may be analyzed. The storage percentage is negative for a storage content less than C_2 and greater than 100% for a storage content greater than C_1.

The *2PER* drawdown duration table shows the number of months of the simulation for which the end-of-month drawdown (storage depletion) exceeds given percentages of the storage capacity of the specified storage zone. Drawdowns are expressed as a percentage of storage capacity as follows.

$$\text{drawdown as percentage of storage} = 100\% - \frac{S - C_2}{C_1 - C_2}(100\%) \qquad (2\text{-}6)$$

TABLES counts and tabulates the number of months during the simulation for which the draw-down defined by Equation 2-6 equals or exceeds 0%, 2%, 5%, 10%, 25%, 50%, 75%, 90%, and 100% of the storage capacity defined by Equation 2-5. This storage drawdown-frequency table is similar to the *2REL* table for water supply diversions and hydropower generation, except the draw-down frequency is expressed as the actual number of months rather than the percentage of the months.

Yield Versus Reliability Relationships

The annual water supply diversion target or hydroelectric energy generation target is entered in field 3 of the water right *WR* record as the input variable *AMT*. Model applications may require computing volume and period reliabilities for a range of different values for *AMT*. The firm yield, defined as the maximum value of *AMT* that has a computed reliability of 100.0 percent, also may be of interest. A table of annual yield, represented by the variable *AMT*, versus reliability, that includes firm yield (100% reliability), may be developed simply by running *SIM* multiple times, manually changing the *AMT* entry in *WR* record field 3 for each run. An option activated by the *FY* record automates this procedure. The model user runs *WRAP-SIM* one time. The model internally repeats the simulation multiple times with the annual target amount being systematically changed for each simulation.

The routine to develop a yield versus reliability relationship is controlled with the firm yield *FY* record. The resulting table is written to the yield-reliability output file. The firm yield is the last entry in the yield-reliability table.

The yield-reliability table reproduced as Table 2-10 is provided to illustrate the automated yield-reliability/firm yield option. The table begins with a list of the water rights for which the target amounts are adjusted. *FYWRID* and *FYGROUP* from *FY* record fields 7 and 8 connect with the water right identifiers in *WR* record field 11 and group identifiers in *WR* record fields 12 and 13. The program is dimensioned to include up to 100 *WR*-record water rights. The water right identifier and two group identifiers are listed for each right on the top of the yield-reliability table. The annual target is divided between the rights by the percentages shown, which are computed based on directly proportioning the *AMT* from their *WR* records. Thus, the first right in the example, which represents a municipal diversion from Jones Reservoir, accounts for 38.78% of the annual target shown in the table.

Each line in the table represents the results of a simulation. The annual target amount *AMT* is the only input variable that changes between simulations. No other features of *WRAP-SIM* are affected. All other features remain in effect.

FYIN(1) entered in field 2 of the *FY* record (0.92 in example) is the fraction of the monthly target that must be met in order for the routine to not declare that month a failure in the computation of period reliability. *FYIN(5)* might be set at 0.92 for an analysis based on the premise that a 8% reduction in water use through emergency demand management measures is acceptable during dry periods. The *FYIN(5)* default is 1.0, meaning the entire target must be met in order to not declare a failure in meeting the target that month. *FYIN(1)* affects only the period reliability (last two columns of table). It is not used in the volume reliability computations (columns 3, 4, 5). The firm yield criterion for stopping the iterative routine is based on reaching a total shortage of essentially zero, defined as less than 0.05 units (typically acre-feet/year). *If FYIN(1)* is non-zero, the 100% period reliability yield may be larger than the 100% volume reliability yield. Both are shown in the yield-reliability table. In the example with *FYIN(5)=0.92*, the volume reliability firm yield is 116,720 ac-ft/yr and the period reliability firm yield is 116,800 ac-ft/yr.

The yield-reliability table shown as Table 2-10 is created with the following entries on a *FY* record:

FYIN(1) = 0.92
FYIN(2) = 200,000 acre-feet/year
FYIN(3) = 10,000 acre-feet/year
FYIN(4) =   1,000 acre-feet/year
FYIN(5) =   100 acre-feet/year
Either FYWRID = Jones Reservoir   and/or   FYGROUP = yield

Table 2-10
Example Yield-Reliability Output File


```
       Yield Versus Reliability Table for the Following Water Right(s):

          38.782 percent: Jones Reservoir    municipa  yield
          52.148 percent: Jones Reservoir    industri  yield
           9.070 percent: Jones Reservoir    irrigati  yield
```

If more than one right, the target amount is distributed using the percentages
shown above. The total number of periods is 696. The period reliability is the
percentage of the periods for which at least 92.0 percent (FY record field 2;
default=100%) of the target is supplied. The table below ends with the maximum
target that results in a mean annual shortage of less than 0.05 units.

Iteration	Level	Annual Target	Mean Shortage	Mean Actual	Volume Reliability (%)	Periods Without Shortage	Period Reliability (%)
1	0	200000.0	16025.7	183974.3	91.99	630	90.52
2	1	190000.0	13327.9	176672.1	92.99	639	91.81
3	1	180000.0	10741.8	169258.2	94.03	646	92.82
4	1	170000.0	8321.3	161678.7	95.11	656	94.25
5	1	160000.0	6077.6	153922.4	96.20	664	95.40
6	1	150000.0	4533.4	145466.6	96.98	672	96.55
7	1	140000.0	3274.3	136725.7	97.66	677	97.27
8	1	130000.0	1828.7	128171.3	98.59	683	98.13
9	1	120000.0	432.1	119567.9	99.64	692	99.43
10	1	110000.0	0.00	110000.0	100.00	696	100.00

11	2	119000.0	284.9	118715.1	99.76	694	99.71
12	2	118000.0	162.5	117837.5	99.86	695	99.86
13	2	117000.0	40.5	116959.5	99.97	695	99.86
14	2	116000.0	0.00	116000.0	100.00	696	100.00

15	3	116900.0	25.6	116874.4	99.98	695	99.86
16	3	116800.0	10.7	116789.3	99.99	696	100.00
17	3	116700.0	0.00	116700.0	100.00	696	100.00

18	4	116790.0	9.24	116780.8	99.99	696	100.00
19	4	116780.0	7.76	116772.2	99.99	696	100.00
20	4	116770.0	6.27	116763.7	99.99	696	100.00
21	4	116760.0	4.78	116755.2	100.00	696	100.00
22	4	116750.0	3.29	116746.7	100.00	696	100.00
23	4	116740.0	1.80	116738.2	100.00	696	100.00
24	4	116730.0	0.32	116729.7	100.00	696	100.00
25	4	116720.0	0.00	116720.0	100.00	696	100.00

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The iterative simulations are organized as follows.

1. The total annual target amount *AMT* equals *FYIN(2)* (=200,000 ac-ft/yr) from the *FY* record for the first simulation. *AMT* for the initial and all subsequent iterations is distributed to multiple water rights in proportion to *WR* record field 3 *AMT*s, with resulting percentages listed at the top of the table, to determine the initial individual *AMT* for each of the rights.

2. The total annual target amount *AMT* is decreased by *FYIN(3)* from the *FY* record for each subsequent level 1 iteration until either no shortages occur or the target is finally decreased to zero or less.

3. If both *FYIN(4)* and *FYIN(5)* are zero, the computations stop. If *FYIN(4)* is not zero, the computations proceed to level 2. In the example, since *FYIN(4)* of 1,000 ac-ft has been entered on the *FY* record, the computations proceed to level 2.

4. For level 2, the initial target amount *AMT* is set equal to the next-to-last target amount from the level 1 iterations (120,000 ac-ft). *AMT* is decreased by *FYIN(4)* (1,000 ac-ft) for each level 2 iteration until either no shortages occur or the target *AMT* reaches zero.

5. If *FYIN(5)* is zero, the computations stop without proceeding to levels 3 and 4. Otherwise, level 3 iterations are performed using *FYIN(5)* as the incremental decrease in *AMT*. For the example, *FYIN(5)* is 100 ac-ft.

6. If *FYIN(5)* is not zero, upon completion of the level 3 iterations, an extra level 4 set of iterations is performed with the incremental decrease set at 10 percent of *FYIN(5)*.

   The *FY* record computations are performed for only one annual diversion or hydropower amount. A single annual target amount is adjusted during the iterative routine. However, this amount may be shared by two or more water rights (*WR* records). The *FY* record routine is dimensioned for up to 100 water rights. The water right identifier in *FY* record field 7 is matched with the identifiers entered in water right *WR* record field 11. The water right group identifier in *FY* record field 8 is matched with the identifiers entered in water right *WR* record fields 12 and 13. The annual amount is divided between multiple rights in proportion to the amounts *AMT* entered in field 3 of the *WR* records. For those rights designated by *FYWRID* and *FYGROUP* on the *WR* record, this is the only use made of the amounts entered in field 3 of their *WR* records. If only one right is designated by the *FY* record, an amount entered in field 3 of its *WR* record is not used for anything in the computations.

Chapter 2 Overview

CHAPTER 3
HYDROLOGY FEATURES

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

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

- simulating capabilities for fulfilling specified water management and use requirements within the context of the water rights system

- during an assumed hypothetical repetition of historical hydrology represented by sequences of monthly naturalized streamflows and reservoir net evaporation-precipitation rates covering a selected hydrologic period-of-analysis.

The future is of concern, rather than the past. However, future hydrology is unknown. Historical streamflows and reservoir evaporation less precipitation rates are adopted as being representative of the hydrologic characteristics of a river basin that can be expected to continue into the future. A typical hydrologic period-of-analysis used for studies in Texas is 1940 to the present. This period includes the 1950-1956 most severe drought-of-record as well as a full range of fluctuating wet and dry periods. Water resources are highly variable and highly stochastic (random), subject to extremes of droughts and floods as well as continuous more normal fluctuations. Major droughts typically involve long periods with sequences of many months of low flows. A basic premise of the conventional modeling approach is that historical naturalized streamflows and evaporation-precipitation rates for an adequately long period-of-analysis captures the essential statistical characteristics of basin hydrology.

WRAP is a river/reservoir system model with little capability for simulating groundwater or surface/subsurface water interactions. However, some interactions between streamflow and subsurface water may be modeled. Channel loss features are described in this chapter. Water supply return flows covered in Chapter 4 may originate from groundwater sources. Groundwater return flows may be modeled using constant inflow *CI* records or as a *WR* record type 7 right. In TNRCC/HDR studies of the San Antonio, Guadalupe, and Nueces River Basins, management scenarios for the Edwards Aquifer have been reflected in *WRAP* as spring flow adjustments to naturalized streamflows. Changes in spring flows associated with aquifer management plans, simulated with a groundwater model, were treated as adjustments to *WRAP* streamflows.

Naturalized Streamflow

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

Developing naturalized flows typically represents a major portion of the effort required for a water availability modeling study. The extent to which observed historical flows are naturalized is based largely on judgment. Sequences of monthly flows representing natural hydrology are typically developed by adjusting recorded flows at gaging stations to remove the impacts of upstream major reservoirs, water supply diversions, return flows from surface and ground water sources, and possibly other factors. In most typical major river basins, there are numerous smaller reservoirs, but most of the storage capacity is contained in a relatively few large reservoirs. A decision is required regarding which of the reservoirs to include in the adjustments. Other types of adjustments may be made as well. For example, land use changes such as clearing forests and urbanization may significantly affect streamflow. In extensively developed river basins, quantifying and removing all effects of human activities is not possible. For sites with relatively undeveloped watersheds, little or no adjustments may be necessary.

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

1. developing sequences of naturalized flows at stream gaging stations

2. reconstituting flows for gaps of missing data and extending record lengths

3. distributing naturalized flows from gaged to ungaged locations

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

WRAP-HYD writes naturalized flows as a set of inflow *IN* records for input to *WRAP-SIM*. *WRAP-HYD* provides various hydrology data compilation capabilities, which among others include options for:

1. converting observed gaged streamflows to naturalized streamflows

2. distributing naturalized flows from gaged to ungaged locations using techniques described later in this chapter

3. otherwise adjusting naturalized flows

WRAP-SIM requires sequences of naturalized flows at each control point for each month of the hydrologic period-of-analysis. For each control point, naturalized streamflows must be either:

1. provided as *WRAP-SIM* input on inflow *IN* records

or

2. computed within *WRAP-SIM* from flows at one or more other control points using those same flow distribution techniques that are incorporated in *WRAP-HYD*.

WRAP-SIM imposes no limits on the length of the period-of-analysis. *WRAP-HYD* is limited to working with sequences of flows not exceeding a set length, currently dimensioned at 125 years. Longer periods can be subdivided for multiple runs. An example of a typical period-of-analysis is 1940 to 1999. Any units may be used in combination with appropriate conversion factors. Typical English units are acre-feet/month. Typical metric units are million cubic meters per month.

Streamflow Naturalization Adjustments within WRAP-HYD

As discussed in the *Users Manual*, *WRAP-HYD* includes the following features designed to assist in the process of converting observed flows to naturalized flows.

1. options for modifying streamflows by adding or subtracting any number of data sets of flow adjustments (*AS* record and associated *FA* or *CI* records)

2. options for developing streamflow adjustments for the historical effects of reservoirs (AS record followed by RS and SC records)

3. options for applying a regression equation to modify streamflows (*EQ* record)

The objective of the streamflow adjustment routines in *WRAP-HYD* is to provide a flexible generic set of options to facilitate adjusting a set of streamflows to reflect changes in river basin development. The most typical application is converting historical streamflows to naturalized flows. However, conversions between other scenarios of watershed development may also be of interest. *WRAP-HYD* is designed to be flexible for application to various situations.

WRAP-HYD AS/FA/CI-Record Adjustments to be Added to Streamflows

Adjustment data sets are read by *WRAP-HYD*, multiplied by a user-specified factor, and added to the streamflows. The adjustment data sets are simply time series of numbers to be combined with the streamflows. The numbers may be positive or negative. Any number of data sets may be applied at a particular control point. The data sets are added at a specified control point and optionally at all downstream control points. Channel losses may be reflected in cascading the adjustments downstream.

Typically, the original unadjusted streamflows will be historical gaged flows. Typical adjustments include historical water supply diversions, return flows from surface and/or groundwater withdrawals, reservoir storage changes and evaporation/precipitation. Other types of adjustments may be added or subtracted as well. For example, as previously mentioned, changes in spring flows determined with a groundwater model and associated with alternative aquifer management strategies have been treated as adjustments to naturalized streamflows.

Any number of the following types of adjustments may be combined with the streamflows at a control point and its downstream control points.

1. The *WRAP-HYD AS* record includes a constant to be added to streamflows as well as a multiplier factor.

2. Sets of 12 adjustments for the 12 months of the year input on constant inflow *CI* records may be added to streamflows within either *WRAP-HYD* or *WRAP-SIM*.

3. Time series of adjustments spanning any number of years are entered on flow adjustment *FA* records for *WRAP-HYD*. *WRAP-SIM* contains a similar routine with fewer options.

4. Adjustments for the effects of reservoirs are computed within *WRAP-HYD*.

Adjustments for the effects of reservoirs are computed within *WRAP-HYD* and then handled within the program the same as the other adjustments read from input files.

WRAP-HYD RS-Record Adjustments for the Effects of Reservoirs

Adjustments for the effects of reservoirs on streamflow include the following user-specified component parts that are combined to obtain a total adjustment that is applied to the streamflows at the control point of the reservoir and optionally at each downstream control point.

1. increases in reservoir storage content (Default is to add to streamflow.)

2. decreases in conservation storage content (Default is to subtract from streamflow.)

3. decreases in storage above a specified storage capacity which represent spills or flood releases
   (Default is to subtract from streamflow.)

4. net evaporation-precipitation volumes (Default is to add to streamflow.)

5. portion of naturalized streamflow representing runoff from land area covered by a reservoir that would have occurred without the reservoir (Default is to add to streamflow.)

The five types of adjustments are added together to obtain a total adjustment to be added to streamflows just like the other adjustments described in the previous section. An optional table showing each component part of the total adjustment and related data including water surface area and runoff depth may be created for the model-user's information.

WRAP-HYD allows each of the five component adjustments to be either zero, negative, or positive, as specified on the *RS* record, with the defaults as shown in parenthesis above. The default for component adjustments 1, 4, and 5 is to make naturalized flows greater than the observed flows. By default, adjustments 2 and 3 decrease the streamflows. The defaults represent the typical situation of converting historical gaged streamflows to naturalized flows. However, flexibility is provided to model various situations. For example, water supply diversion data, normally input on *FA* records, may not be available. Decreases in conservation storage is caused by evaporation and downstream releases as well as lakeside diversions. However, if conservation storage decreases are caused primarily by diversions, and diversion data are unavailable and thus not included in the naturalization process, the decreases in conservation storage may be omitted as partial compensation for the missing *FA* record diversion data.

Input data required to compute adjustments for the effects of reservoirs on streamflow include:

- historical end-of-month storage content (*SC* records) used to compute changes in storage

- storage-area relationships (*SV/SA* or *RS* records) and net evaporation-precipitation rates (*EV* records) used to compute net evaporation-precipitation volumes

WRAP-HYD determines the increase or decrease in reservoir storage content during each month from the end-of-month storage contents entered on *SC* records. Storage increases, decreases, or both may be included in the adjustment. Storage decreases occurring above and below a specified storage capacity are determined separately. The user-specified storage capacity is typically the full conservation storage. Storage above this capacity represents flood storage, and corresponding storage reductions represent spills or flood releases.

Net evaporation-precipitation volumes are computed by applying rates (depth/month) to the average water surface area during the month determined by combining storage contents with the storage-area relationship for the reservoir.

The optional adjustment for the portion of naturalized streamflow representing runoff from the land area covered by a reservoir that would have occurred without the reservoir is conceptually the same as the drainage area method for transferring flows. The adjustment is computed by multiplying the naturalized streamflow by the ratio of reservoir water surface area to watershed drainage area. Since the current value for naturalized flow at the control point is used, this adjustment should be made after other relevant adjustments. As discussed later in the *Reservoir Evaporation-Precipitation* section of this chapter, similar reservoir site area runoff adjustments are included in both *WRAP-HYD* and *WRAP-SIM*.

WRAP-HYD EQ-Record Adjustments to Streamflows

Streamflows (Q) may also be adjusted by applying either of the following equations:

$$Q_{adjusted} = a\,Q^b + c \tag{3-1}$$

$$\Delta Q_{adjustment} = (a\,Q^b + c) - Q \tag{3-2}$$

Equation 3-1 converts the flow Q to a $Q_{adjusted}$ at a specified control point without considering other control points. Equation 3-2 computes an adjustment $\Delta Q_{adjustment}$ to be added to the flows at the specified control point and optionally at downstream locations just like the previously discussed *AS* record adjustments. Channel losses and other options may be applied in cascading the $\Delta Q_{adjustment}$ just like with the *AS* record adjustments.

The regression equation feature may be used in various ways. It was incorporated into *WRAP-HYD* particularly for use with a precipitation-runoff watershed simulation model such as the *Soil and Water Assessment Tool (SWAT)* developed at the USDA Agricultural Research Service and TAMU Agricultural Experiment Station Research Center in Temple, Texas. The precipitation-runoff model may be used to quantify the effects of watershed land use changes. *SWAT* and *WRAP* have also been applied in combination on a research project assessing the impacts of climate change

on water management. Streamflow is computed with *SWAT* for given precipitation and other climatic data and watershed characteristics. Changes in land use are modeled by changing watershed parameter values. Changes in climate are reflected in precipitation, temperature, and other climatic variables. The precipitation-runoff model is applied to compute streamflows for scenarios with and without climate or watershed changes. Regression analyses are then applied to flows computed with the two different scenarios to obtain a set of *a*, *b*, *c* coefficients for input to *WRAP-HYD*. As discussed later in this chapter, a regression equation likewise may be used with *FD/FC* records to distribute flows from gaged to ungaged locations.

Allocation of Streamflow within WRAP-SIM

The *WRAP-SIM* simulation process is outlined in Figure 2-1 of Chapter 2. The simulation begins with naturalized streamflows. For each month of the simulation, streamflows are allocated to meet the water rights requirements described in Chapter 4. **Regulated** and **unappropriated flows** are computed for each **control point** for each month of the period-of-analysis. **Available flows** and **streamflow depletions** are computed for each **water right** for each month of the period-of-analysis. The basic streamflow-related variables computed within *WRAP-SIM* are defined as follows.

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

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

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

Streamflow depletions are the streamflow amounts appropriated to meet diversion requirements, account for reservoir net evaporation-precipitation, and/or refill reservoir storage. A streamflow depletion in a given month will often include refilling of reservoir storage capacity depleted during previous months. A negative streamflow depletion means the *EV* record precipitation added to the streamflow exceeds the evaporation, diversion, and reservoir refilling that deplete the streamflow. Each streamflow depletion is associated with a particular water right. Unappropriated flows are the portions of the naturalized flows still remaining after accounting for streamflow depletions, instream flow requirements, and return flows for all water rights.

A *WRAP-SIM* simulation begins with hydrologic period-of-analysis sequences of monthly naturalized (unregulated) flows at each control point provided as input. Regulated and unappropriated flows are computed from the naturalized flows through a series of adjustments reflecting the effects of water rights requirements and associated reservoir storage. As illustrated in Figure 2-1, the *WRAP-SIM* water allocation computations are performed in a water rights loop embedded with a period (monthly time step) loop. *WRAP-SIM* computes available flows and streamflow depletions associated with each water right and unregulated and unappropriated streamflows associated with each control point. As each water right is considered, the available streamflow is determined based on yet uncommitted flows at its control point and all downstream control points. After the streamflow depletion for the right is determined, the flows at the control point and all downstream control points are adjusted for the depletion and return flows.

Reservoir Evaporation-Precipitation

Evaporation from a reservoir and precipitation falling directly on the reservoir water surface are combined as a net evaporation minus precipitation. Net evaporation less precipitation volumes are computed by multiplying the reservoir water surface area by net evaporation-precipitation rates provided on *EV* records in dimensions of depth/month. Various units may be used. Typical units include water surface area in acres, evaporation-precipitation rates in feet/month, and volumetric rates in acre-feet/month. Routines that compute evaporation-precipitation volumes are incorporated in both *WRAP-HYD* and *WRAP-SIM*.

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

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

Adjusted Net Evaporation-Precipitation

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

A traditional approach adopted in the past in Texas has been to include a pre-reservoir precipitation-runoff adjustment in the net evaporation minus precipitation rates input on the *EV* records. Previously, the Texas Water Development Board (TWDB) maintained an adjusted net reservoir surface evaporation rate database, where the net rate was the evaporation rate minus the

effective rainfall rate, which is rainfall over the reservoir site less the amount of runoff under preproject natural conditions. However, the TWDB no longer maintains the adjusted net evaporation database, because the agency considers the runoff adjustment techniques reflected in this previous database to be overly simplified and too approximate.

As discussed in the *Users Manual* and earlier in this chapter, *WRAP-HYD* includes an option to include an adjustment for the runoff from the land area covered by a reservoir that would have occurred without the reservoir. This adjustment may be incorporated with other adjustments in removing the historical effects of reservoirs in the process of converting gaged streamflows to naturalized flows. *WRAP-SIM* also includes an option for accounting for the portion of the reservoir surface precipitation that is already reflected in the naturalized streamflow inflows. In a typical application mode, the *WRAP-HYD* adjustment is added to historical streamflows to determine naturalized streamflows. In *WRAP-SIM*, the adjustment reduces available water amounts to prevent *double-counting* which would occur inappropriately if the runoff from the reservoir site is included in both the naturalized streamflows (*IN* records) and precipitation falling on the reservoir water surface (*EV* records).

The procedures in *WRAP-SIM* for adjusting net evaporation-precipitation depths for runoff from reservoir sites are outlined as follows.

- Net evaporation minus precipitation depths are input on *EV* records.

- A precipitation-runoff adjustment term is computed within *WRAP-SIM* to prevent *double-counting* the reservoir surface precipitation that is already in the *IN* record naturalized flows. *JD* record field 10 (*EPADJ*) and *CP* record field 9 (*EWA*) activates this option. The *JD* record field 10 sets the default option applied to all control points for which the *CP* record field 9 is left blank. An entry for *EWA* on a *CP* record overrides the default option set by *EPADJ* on the *JD* record. If both the *JD* record field 10 and *CP* record field 9 are blank, the precipitation -runoff adjustment is simply not applied.

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

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

1. A streamflow per unit drainage area or runoff depth (in feet/month) is computed by dividing the total or incremental monthly naturalized streamflow (in acre-feet/month) by the watershed area from the *CP* record or *FD/WP* records.

2. The runoff depth computed in step 1 above is added to the net evaporation-precipitation rate read from an *EV* record. Thus, the adjusted net evaporation-precipitation rate is the evaporation rate minus precipitation rate plus rainfall-runoff depth computed in step 1 above.

3. The algorithms for determining net evaporation volumes and performing the reservoir volume accounting remain unchanged. The only difference is that the *EV* record net evaporation-precipitation rates input to the computations have been adjusted as noted above. The net evaporation-precipitation volume is determined by multiplying the reservoir water surface area by the adjusted net evaporation-precipitation depth.

Channel Losses

Channel losses represent the portion of the streamflow in the reach between two control points that is loss through infiltration, evapotranspiration, and diversions not reflected in the water rights. The naturalized flows input on *IN* records are typically determined based on adjusting observed flows at gaging stations to remove the effects of human water management. Thus, the naturalized flows should already reflect natural channel losses. In *WRAP-SIM*, a streamflow depletion (diversion and/or refilling reservoir storage) at a control point results in a reduction in the water available at that control point and all downstream control points. In reality, a portion of the water diverted or stored may not reach the downstream sites anyway due to channel losses. Also, diversion return flows and reservoir releases may be diminished prior to reaching downstream locations. Channel losses are included in several *WRAP-SIM* routines to address these situations. Channel losses may also be included in the *WRAP-HYD* streamflow naturalization adjustments discussed earlier in this chapter. A channel loss option is also included in the flow distribution methods, described later in this chapter, incorporated in both *WRAP-HYD* and *WRAP-SIM*.

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

$$L \ = \ C_L \ Q_{upstream} \tag{3-3}$$

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

Channel Losses in WRAP-SIM

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

1. Channel losses reduce the streamflows associated with return flows, *CI-* and *FA*-record positive inflows, releases from reservoir storage for downstream diversions or hydroelectric power generation. These losses represent **decreases** in streamflows to result from incorporation of channel losses in the model.

2. Channel loss **credits** represent the *"reduction in the reduction"* in streamflows at downstream locations associated with upstream streamflow depletions for diversion and storage rights and *CI*-record outflows (negative inflows). **Credits** represent **increases** in streamflows to result from incorporation of channel losses in the model. In the simulation computations, flows at downstream control points are reduced by the amount of upstream streamflow depletions for diversions and filling reservoir storage. **Credits** represent the amount of the streamflow depletion that would not have reached the downstream location anyway due to channel losses.

Both channel loss credits and channel losses are computed and written to the output file within the *WRAP-SIM* water rights and period loops. The total of the channel loss credits for each month at each control point are written in field 11 of the control point output record. Likewise, the total monthly channel losses are written in field 12 of the control point records in the *WRAP-SIM* output file. Program *TABLES* reads the *WRAP-SIM* output file and builds user-specified tables which may include the channel losses and credits. The difference between the credits tabulated by a *2CLC* record and losses tabulated by a *2CLO* record is as follows.

- The monthly flows in a table developed by a channel loss credit *2CLC* record for a specified control point represent the total channel losses in the reach below the control point associated with streamflow depletions at upstream control points for diversions and refilling reservoir storage. These loss credits represent channel losses reflected in the *IN*-record streamflows that did **not** actually occur in the simulation because the diversion or reservoir refilling reduced the downstream flows and corresponding channel losses.

- The monthly flows in a table developed by a channel loss *2CLO* record for a specified control point represent the total channel losses in the reach below the control point associated with diversion return flows, *CI* record inflows, and releases from reservoir storage. These flows represent reductions in streamflow in the model.

Computational algorithms related to channel losses are incorporated in subroutines *INFADJ*, *AVALB*, and *FLDIST* and at several places in the main program. As previously discussed, in *WRAP-SIM*, regulated flows and unappropriated flows are computed through a series of cumulative adjustments starting with the naturalized flows provided as input. The streamflows change in response to the effects of each water right as it is considered in turn in the water rights computation loop. The channel loss computations are performed in conjunction with (1) determining the amount of water available to a right and (2) making adjustments to regulated and unappropriated flows at each downstream control point reflecting the effects of upstream:

- streamflow depletions for diversions and/or refilling of reservoir storage
- constant inflows or outflow input on *CI* or *FA* records
- return flows

- releases from storage in secondary reservoirs at upstream control points for diversions downstream
- releases from reservoir storage for hydroelectric power generation
- reservoir spills associated with seasonal rule curve operations

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

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

The channel loss credit computations for adjustments to regulated and unappropriated flows associated with streamflow depletions for diversion and storage rights are described below. These computations are performed in subroutine *INFADJ*. Similar algorithms in the main program compute channel losses associated with return flows and releases from reservoir storage. Channel losses are also considered in another computation. In the water rights computational loop, as each right is considered in turn, the allocation computations begin by calling subroutine *AVALB* to determine the amount of water available to the right. The amount of water available depends on yet unappropriated flows at the control point of the water right and at all downstream control points. Channel loss credits for streamflow depletions associated with the right are included in determining the amount of water available to the right.

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

$$A_{adjusted} = A - D \qquad (3\text{-}4)$$

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

$$A_{adjusted} = A - (D - C_L D) = A - (1 - C_L) D \qquad (3\text{-}5)$$

For control points in series, the channel losses in each individual reach ($L_i = C_{Li} D$) are considered in adjusting water availability to reflect upstream diversions and storage. The water available A at the *Nth* control point below the streamflow depletion is adjusted as follows, where C_{L1}, C_{L2}, C_{L3}, ..., C_{LN} denote the channel loss coefficients for each of the N individual reaches between the control point at which the streamflow depletion D occurs and the control point at which the amount of available water A is being adjusted.

$$A_{adjusted} = A - [(1 - C_{L1})(1 - C_{L2})(1 - C_{L3}) ... (1 - C_{LN})] D \qquad (3\text{-}6)$$

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

Channel Losses in WRAP-HYD

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

1. streamflow naturalization adjustments

2. distribution of flows from gaged to ungaged locations

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

$$F_{adjusted} = F + A_F \qquad (3\text{-}7)$$

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

$$F_{adjusted} = F + [(1\text{-}C_{L1})\,(1\text{-}C_{L2})\,(1\text{-}C_{L3}) ... (1\text{-}C_{LN})]\, A_F \qquad (3\text{-}8)$$

Distribution of Naturalized Flows from Gaged to Ungaged Control Points

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

Incremental Watersheds

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

1. The incremental flow at the gage is computed by subtracting the total flow at the gage from the sum of flows at appropriate upstream gages.

2. The incremental flow at the gage, computed in step (1), is distributed to the ungaged site using one of the alternative methods described later.

3. The incremental flow at the ungaged site, computed in step (2), is added to the flows at appropriate upstream control points to obtain the total flows at the ungaged site.

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

The schematic and equations shown in Figure 3-1 illustrate the scheme by which *WRAP-HYD* and *WRAP-SIM* allow the user to define incremental watersheds on *FD* records for use in distributing flows. Figure 3-1 also serves as the schematic for an example in Appendix J that demonstrates flow distribution features. In Figure 3-1, flows are known at gaged control points (CP's) J, K, L, M, and N and must be computed at ungaged control points I, II, III, and IV. The *WRAP* methodology allows the user to select the gaged CP's from which to distribute flows. Flows at either of the four ungaged sites (CP's I, II, III, IV) may be computed by distributing total flows from either of the five gaged CP's or alternatively from the incremental local watershed above CP N. For example, flow and drainage area equations are shown in the figure for computing flows at CP I using the incremental watersheds above CP I and CP N.

For each ungaged control point, there is one gaged (known-flow) control point from which flows are transferred. Other gaged CP's located upstream may be used to define the local incremental watersheds for both the gaged source CP and the ungaged CP. The following information is provided on the flow distribution *FD* record of the control point for which flows are being generated.

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

The gaged control point from which flows are computed will be called the source CP. As illustrated by Figure 3-1, the ungaged site may be either upstream of the source CP, downstream of the source CP, or on a different tributary. The maximum number of upstream CP's that may be used to compute incremental flows at the source CP is a dimension limit which can readily

changed in the Fortran code. Any of the upstream control points may also be used to define the incremental watershed above the ungaged CP. The variable *NGAGE* on the *FD* record indicates how many of the gaged CP's above the source CP are also located above the ungaged site. For example, the flows at CP I in Figure 3-1 may be determined from the flows at source CP N. Upstream CP's K, J, M, and L are listed on the *FD* record to define an incremental watershed for source CP N. *NGAGE(I)* is 2, indicating that the first two upstream CP's listed (CP's K and J) define the incremental watershed above ungaged CP I. *NGAGE(II)* is 4 for transferring incremental flows below J-K-L-M from N to II. *NGAGE(III)* is zero for computing flows at control point III from either total or incremental flows at control point N.
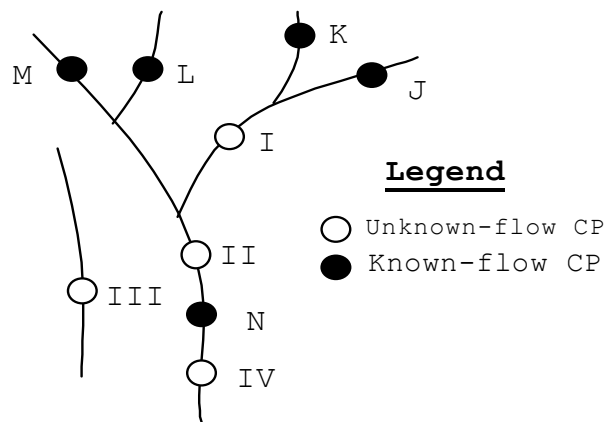
$$DAUG(I) = DA(I) - DA(J) - DA(K)$$
$$DAGAGE(N) = DA(N) - DA(J) - DA(K) - DA(L) - DA(M)$$

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

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

Figure 3-1. **Gaged (Known-Flow) and Ungaged (Unknown-Flow) Control Points**

A *NGAGE* of -1 on a *FD* record indicates that flows at an ungaged site are computed from flows at a source control point located upstream. For example, referring to Figure 3-1, for *NGAGE(IV)*=-1, the incremental flow at IV [QUG(IV)] is computed as a function of incremental or total flow at N [QGAGE(N)] and added to the total flow at N [Q(N)] to obtain the total flow at IV [Q(IV)], where:

$$DAUG(IV) = DA(IV) - DA(N)$$
$$Q(IV) = QUG(IV) + Q(N)$$

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

Flow Distribution Methods

Methods for distributing naturalized streamflows from gaged or known-flow locations to ungaged sites are documented by Wurbs and Sisson (1999). Several flow distribution options in *WRAP-HYD* and *WRAP-SIM* are specified by variable *INMETHOD(cp)* on the *CP* record. Input parameters are provided on flow distribution coefficients *FC* and watershed parameter *WP* records. The flow distribution methods may be applied to either incremental or total flows. These methods are based on either:

- drainage area ratio R_{DA} $\qquad Q_{ungaged} = Q_{gaged} R_{DA}$ $\qquad\qquad$ (3-9)

- the regression equation $\qquad Q_{ungaged} = a\, Q_{gaged}{}^{b} + c$ $\qquad\qquad$ (3-10)

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

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

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

$$Q_{ungaged} = Q_{gaged}\left(\frac{R_{DA}}{1 - R_{DA}C_L}\right)$$
$\qquad\qquad$ (3-11)

The input variable *INMETHOD(cp)* on the *CP* record indicates the method by which flows are computed for ungaged control point *cp*. Option 1 indicates that the naturalized flows for the control point are input in the inflow *IN* record file. Option 2 consists of repeating the flows input for another control point, possibly multiplied by the multiplication factor entered on the CP record. The other options involve flow distribution methods that are described in subsequent sections. The *INMETHOD(cp)* options are as follows.

0,1　　　*IN* records are input for this control point.

2　　　Flows from another control point are repeated without change except for multiplier.

3　　　Equation 3-10 is used:　$Q_{ungaged} = a\,(Q_{gaged})^b + c$

4　　　The modified NRCS CN method is used. The computed flows at the ungaged CP are limited to not exceed the flows at the gaged (known-flow) control point.

5　　　The modified NRCS CN method is used. The computed flows at the ungaged CP are not constrained to not exceed the flows at the gaged (known-flow) CP.

6　　　Equation 3-10 incorporating a channel loss coefficient into the drainage area ratio method is used. Drainage areas are entered on *WP* records. C_L is from *CP* record.

7　　　Simple ratio of drainage areas from *WP* records is used.　　$Q_{ungaged} = Q_{gaged}\,R_{DA}$

8　　　An iterative algorithm incorporates channel losses in the NRCS CN method.

Generalized Regression Equation (Option 3)

Option 3 consists of distributing flows using Equation 3-10

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

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

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

$$Q_{ungaged} = a\,Q_{gage} \tag{3-12}$$

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

$$a = R_{DA} = \frac{A_{ungaged}}{A_{gage}} \tag{3-13}$$

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

$$a = \left(\frac{A_{ungaged}}{A_{gage}}\right)^{N1}\left(\frac{M_{ungaged}}{M_{gage}}\right)^{N2}\left(\frac{CN_{ungaged}}{CN_{gage}}\right)^{N3}\left(\frac{Other_{ungaged}}{Other_{gage}}\right)^{N4} \tag{3-14}$$

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

$$a = \left(\frac{A_{ungaged}}{A_{gage}} \right) \left(\frac{M_{ungaged}}{M_{gage}} \right) \left(\frac{CN_{ungaged}}{CN_{gage}} \right) \left(\frac{Other_{ungaged}}{Other_{gage}} \right) \qquad (3\text{-}15)$$

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

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

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

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

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

$$Q \;=\; \frac{(P-0.2S)^2}{P+0.8S} \qquad \text{if } P \ge 0.2S \qquad (3\text{-}16)$$

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

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

where Q denotes runoff volume-equivalent in inches, P is precipitation depth in inches, S is the maximum potential retention, and CN is the curve number.

The modified version of the NRCS CN method adapted to distributing monthly flows is described as follows. *P* is computed for the gaged watershed using Equation 3-16, given the naturalized flow *Q* and the *CN* for the gaged watershed. This *P* is multiplied by the ratio of mean precipitation ($M_{ungaged}/M_{gage}$) and substituted back into Equation 3-16 with the appropriate *CN* to determine *Q* for the ungaged site. Thus, the algorithm consists of the following computational steps performed for each month.

Step 1: The flow at the gage is divided by the drainage area A_{gage} and multiplied by a unit conversion factor to convert to an equivalent depth Q_{gage} in inches.

Step 2: Q_{gage} is input to the curve number equation (Equation 3-16) to obtain P_{gage} in inches. An iterative method is required to solve Equation 3-16 for P. This approximation for precipitation depth is assumed to be applicable to the ungaged subwatershed as well as the gaged watershed. Base flow is being distributed along with storm runoff, all in the same proportion.

Step 3: If the long-term mean precipitation varies between the watershed and subwatershed, the precipitation depth may be adjusted by multiplying P_{gage} by the ratio of the long-term mean precipitation depth of the subwatershed to that of the watershed to obtain a $P_{ungaged}$ adjusted in proportion to mean precipitation.

$$\text{adjusted } P_{ungaged} = P_{gage}\left(\frac{M_{ungaged}}{M_{gage}}\right) \tag{3-17}$$

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

Step 4: $P_{ungaged}$ is input into Equation 6-16 to obtain $Q_{ungaged}$ in inches. $Q_{ungaged}$ in inches is multiplied by $A_{ungaged}$ and a unit conversion factor to convert to flow.

Unit Conversion for NRCS CN Equation

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

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

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

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

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

If units for streamflow other than acre-feet/month and/or drainage area units other than square miles are used, an appropriate *DEPTHX* is entered on the *XL* record to convert the monthly runoff depth to inches. A conversion factor on the watershed parameter *WP* record allows converting units for watershed area.

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

Curve numbers (CN) and mean precipitation (MP) are used in the CN method for distributing flows from gaged to ungaged control points incorporated in options 4, 5, and 8. Subroutine *FLDIST* distributes flows from gaged to ungaged locations. Subroutine *IACNP* reads the *FD* and *WP* records from the root.DIS file and computes incremental drainage areas (A), curve numbers (CN), and mean precipitation (MP) for use in subroutine *FLDIST*. The CN and MP for a incremental watershed is computed from the CN's and MP's read from the *WP* records for total watersheds. The basic premise in computing the CN and MP for an incremental watershed is that the CN or MP for a total watershed equals the area-weighted average of the values for all its subwatersheds.

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

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

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

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

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

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

Flow distribution is one of several aspects of a *WRAP* simulation for which channel losses may be pertinent. Channel losses are discussed earlier in this chapter. All of the channel loss routines in the model use a channel loss coefficient C_L for the river reach below a control point, that is entered as variable CL(cp) in the *CP* record. C_L is defined by Equation 3-3.

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

1. The incremental flow at the gage is computed by subtracting the total flow at the gage from the sum of flows at appropriate upstream gages adjusted to remove the effects of channel losses.

2. The incremental flows at the gage, computed in step (1), are distributed to the ungaged site using one of the optional methods described here.

3. The incremental flows at the ungaged site, computed in step (2), are added to the flows at appropriate upstream control points, adjusted for channel losses, to obtain the total flows at the ungaged site.

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

Ungaged Control Point Located Upstream of Source Gaged Control Point

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

$$Q_{ungaged} = f(Q_{gaged} + C_L Q_{ungaged})$$ (3-18)

and channel losses are a function of $Q_{ungaged}$ (loss = $C_L Q_{ungaged}$). Thus, $Q_{ungaged}$ is on both sides of Equation 3-18.

This complexity in incorporating channel losses in the flow distribution algorithms is illustrated by referring to Figure 3-1 and assuming that flows at CP I and CP II are computed from either the total or incremental flow at CP N. If incremental flows at N are used, the channel losses in the reaches below M, L, K, J, I, and II are considered in computing the incremental flow at N. The complexity is that the channel loss in the reach below CP II depends upon the unknown flow at CP II. The flow at control point II is a function of flow at N plus channel losses.

$$Q_{II} = f(Q_N + C_L Q_{II})$$

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

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

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

$$\text{equivalent } C_L = (1 - C_{L1}) (1 - C_{L2}) (1 - C_{L3}) \dots (1 - C_{LN}) \tag{3-19}$$

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

- The ungaged site is located upstream of the source gaged control point.

- Channel losses occur in one or more reaches between the ungaged and gaged control points.

Option 6 - Drainage Area Ratio with Channel Losses

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

$$Q_{ungaged} = R_{DA} (Q_{gaged} + C_L Q_{ungaged}) \tag{3-20}$$

for a situation with a ungaged CP located upstream of a gaged CP. R_{DA} is the drainage area ratio ($A_{ungaged}/A_{gage}$), and C_L is the channel loss coefficient. $Q_{ungaged}$ and Q_{gaged} denote the naturalized flow (either total or incremental) at the two control points. ($Q_{gaged} + C_L Q_{ungaged}$) denotes the flow at the gage adjusted to remove the effect of channel losses in the reach between the ungaged and gaged sites. If intermediate control points are located between these locations, the C_L is an equivalent multiple-reach channel loss factor determined as noted earlier. This equation is algebraically rearranged to obtain the previously noted Equation 6-11.

$$Q_{ungaged} = Q_{gaged} \left(\frac{R_{DA}}{1 - R_{DA} C_L} \right) \tag{3-11}$$

INMETHOD(cp) option 6 consists of applying Equation 6-11. The model obtains C_L from the *CP* record for the ungaged control point and the watershed areas from the appropriate *WP* records. For multiple intermediate control points between the gaged and ungaged sites, an equivalent C_L is determined as previously noted. Option 6 is applicable only in situations in which the ungaged control point is located upstream of the gaged control point.

Option 8 - NRCS CN Method with Channel Losses

Referring to Figure 3-1, Options 4 and 5 applying the NRCS CN method is applicable for transferring flow from source CP N to either III or IV. However, Options 4 and 5 are applicable in the situation of the ungaged CP being located above the gaged control point, such as in transferring flows from CP N to CP I and CP II, only if channel loss factors C_L for CP I and CP II are zero. Otherwise, Option 8 is used.

Option 8 is pertinent only in situations in which the ungaged site is located upstream of the gaged site with channel losses occurring in between. Option 8 consists of combining Equations 3-21 and 3-22

$$Q_{ungaged} \ = \ f(Q_{gaged}+C_LQ_{ungaged}) \tag{3-21}$$

$$\text{equivalent } C_L = (1-C_{L1}) \, (1- C_{L2}) \, (1- C_{L3}) \, ... \, (1- C_{LN}) \tag{3-22}$$

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

1. For the initial iteration, the channel loss $C_LQ_{ungaged}$ is set equal to zero, and thus $(Q_{gaged}+C_LQ_{ungaged})$ is set equal to Q_{gaged}.

2. The CN method based on Equations 3-16 and 3-17 is applied following the steps previously outlined identically as with Option 5 to compute an intermediate value for $Q_{ungaged}$.for the given $(Q_{gaged}+C_LQ_{ungaged})$ from steps 1 and 3.

3. Given the $Q_{ungaged}$.computed in step 2 above, $C_LQ_{ungaged}$ and thus $(Q_{gaged}+C_LQ_{ungaged})$ are determined.

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

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

Multipliers and CP Identifiers on CP Record

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

_CP_ records also include the variables _CPIN(cp)_ and _CPEV(cp)_ which specify other control points with flows or net evaporation-precipitation rates, respectively, which are to be used for control point _cp_. Thus, the flow at another control point can be used without change or multiplied by _CPDT(cp,1)_. Also, zero flows can be specified on the _CP_ record.

WRAP-SIM includes an alternative simplified option for dealing with water right diversions and storage at many remote ungaged locations throughout the watersheds above the control points. The watershed flow option supplements the control point network in delineating the location of water rights. All rights are assigned a control point and, in the model computations, affect unappropriated flows and water availability at that control point and downstream control points. Multiple rights may be assigned to the same control point. The watershed flow option is used for rights at locations in the watersheds above their assigned control points. The site in the watershed at which the right is actually located has no *CP* record and is not treated as a control point. *WRAP-SIM* limits water available to each of these rights to the lesser of:

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

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

Use of GIS to Determine Spatial Connectivity and Watershed Parameters

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

In developing the *WRAP* input data sets for the 23 river basins of Texas for the TCEQ *WAM System*, a GIS methodology based on the ESRI software products *ArcView* and *ArcInfo* was developed and applied to determine spatial connectivity and estimate values for watershed parameters (Hudgens and Maidment 1999; Figurski and Maidment 2000; Mason and Maidment 2000). Recent improvements in the ESRI *ArcGIS* software include expanded Arc Hydro capabilities for developing river basin data (Maidment 2002). Olivera et al. (2002) outline use of *Arc Hydro* capabilities within *ArcGIS* with digital elevation models (DEMs) to delineate watersheds and determine drainage areas.

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

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

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

The curve number (CN) database was previously produced by the TAES Blackland Research Center for the HUMUS project by intersecting maps of land use and soil type and combining the results with a CN table to determine the CN for each grid cell.

Negative Incremental Naturalized Streamflows

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

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

Example 3 - Negative Incremental Streamflows

An example is provided in Figure 3-2 and Tables 3-1 and 3-2. Naturalized flows at each control point for a particular month are tabulated in column 2 of Table 3-1 and also shown in the figure. The incremental inflows between each control point and its adjacent upstream control points are shown in column 3. Incremental flows are negative at control point CP-2 (incremental flow = 81-90 = -9) and control point 6 (incremental flow = 80-100-8 = -28). As illustrated by columns 4 and 6 of Table 6-1 and discussed later, negative incremental flows alternatively may be defined considering all control points located either upstream or downstream of a particular control point. As illustrated by columns 5 and 7 and also discussed later, negative incremental flows may be eliminated by adjusting the flows at pertinent control points.

The amount of water available to a water right and the unappropriated streamflow at a control point may be affected by the magnitude of the naturalized streamflows at that control point and all downstream control points. The relevance of flows being smaller downstream than upstream (negative incremental) and associated adjustments are related to the effects on the amount of water available to water rights and the unappropriated flows in the *WRAP-SIM* simulation. Within the water rights loop, for a given month, the amount of 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 at all downstream control points. The computational loop begins with naturalized streamflows. Thus, in the *WRAP-SIM* simulation, negative incremental inflows at downstream locations may reduce the streamflow available at upstream control points. The reduction in water availability may or may not be appropriate, depending on the actual cause of the negative inflows.

Negative incremental flows are of concern primarily because downstream flow conditions affect the amount of water available at upstream locations in the *WRAP-SIM* simulation computations. Referring to Figure 3-2 and column 4 (Option 1: no adjustments) of Table 3-2, the amount of streamflow initially available at control point CP-1 is the lesser of the total streamflows at CP-1 (90 ac-ft), CP-2 (81 ac-ft), CP-4 (100 ac-ft), or CP-6 (80 ac-ft). Thus, the available flow at CP-1 is 80 ac-ft, which is governed by the CP-6 flow that reflects negative incremental flow. Likewise, the available flow at CP-4 is 80 ac-ft. As the water rights computational loop progresses, the amount of water availability to rights at each control point may be further reduced by senior rights.

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

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

WRAP-HYD and *WRAP-SIM* provide optional capabilities for handling the issue of negative incremental inflows. Both programs provide options to write two alternative forms of negative incremental flow data to a file for information. This file facilitates examination of the frequency, magnitude, and location of negative incremental inflows. Both programs also contain routines for

adjusting streamflows to remove negative incrementals. *WRAP-HYD* is limited to creating an adjusted set of *IN* records. *WRAP-SIM* computes the same adjustments but provides greater flexibility for applying adjustments during the course of the simulation.

Channel Losses

As previously discussed, a channel loss factor *CL(cp)* entered in field 10 of the *CP* record is defined by Equation 3-3. *CL(cp)* is used in the various channel loss computations that occur throughout the simulation. Conceptually, if the negative incremental flows are due strictly to channel losses, and the linear channel loss equation accurately models channel losses, negative incrementals are handled automatically within *WRAP-SIM* and are not a concern. Of course, in reality, negative incrementals can not be perfectly explained with a simple linear relationship between channel loss and upstream flow. However, the channel loss routine incorporated in determining the amount of water available for a right may significantly reduce or mitigate the effects of negative incremental flows.

In the example, if *CL(cp)* for control points CP-1 and CP-4 are 0.1 and 0.2, respectively, or greater, the negative incremental flows do not constrain water availability at upstream locations at the beginning of the simulation. In the example, the amount of water available at control point CP-1 for the first water right is 90 ac-ft as shown in column 3 of Table 3-2. The 90 ac-ft at CP-1 is determined as the minimum of the following values.

CP-1:   90

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

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

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

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

CP-4:   100

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

Downstream and Upstream Negative Incremental Flow Adjustments

WRAP-HYD and *WRAP-SIM* negative incremental flow adjustment options are based on two alternative ways of defining negative incremental flow adjustments, referred to as *downstream* versus *upstream* incrementals. The approach for computing the *downstream* incremental flow adjustments associated with a particular control point compares its flow to the flow at each control point located downstream. Negative incremental flows between a control point and its downstream control points are shown in column 4 of Table 6-1. The negative incremental inflow is the greatest difference between the naturalized streamflow at the control point and any control point located physically downstream. The value of negative incremental flow is written as either zero or a negative number indicating the amount that must be subtracted from the flow at that control point to equal the lowest flow occurring at any downstream control point. These downstream negative incremental flow adjustments are added to the naturalized flows in column 2 to obtain the adjusted flows in column 5 of Table 3-1.
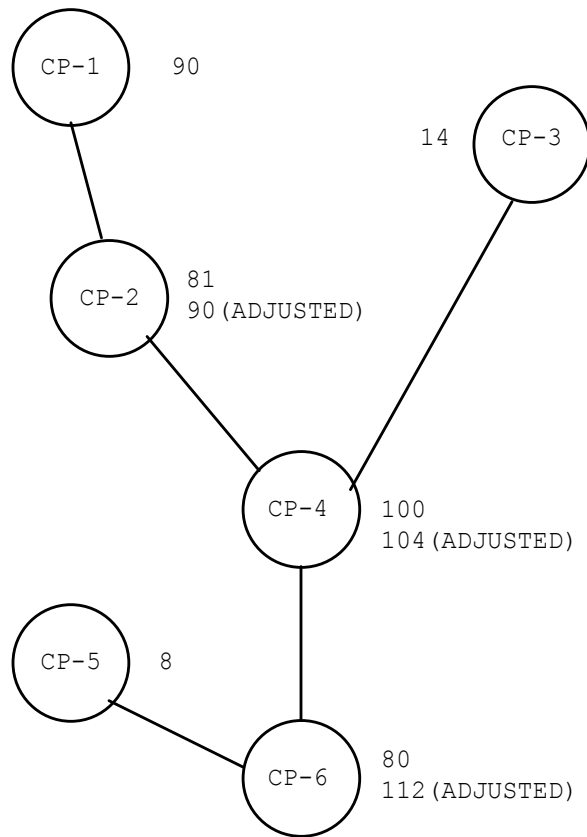
Figure 3-2. **System with Negative Incremental Inflows**

Table 3-1
Incremental Naturalized Streamflow Example

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

Chapter 3 Hydrology

Table 3-2
Available Streamflows for the Example

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

Upstream negative incremental flow adjustments associated with a control point represent the amount that must be added to the flow at that control point to remove all negative incremental flows occurring at all control points located upstream. This form of negative incremental flow is written to the *WRAP-HYD* OUT or *WRAP-SIM* MSS files as either zero or positive, indicating an amount the streamflow at the control point must be increased to alleviate negative incrementals. Upstream negative incremental flow adjustments for the example are shown in column 6 of Table 3-1. These adjustments are added to the naturalized flows to obtain the adjusted flows in column 7.

Writing Negative Incremental Inflow Adjustments to a File

Both *WRAP-HYD* and *WRAP-SIM* include options, specified by variable *NEGINC* on the *JC* or *JD* record, to write the two alternative forms (downstream versus upstream illustrated by columns 4 and 6 of Table 3-1) of negative incremental inflow adjustments to a file for information. The model user may examine this file to determine the extent of negative incrementals in the naturalized streamflow data set (*IN* records). Both programs output these data in the same format to the message file (*WRAP-SIM*) or output file (*WRAP-HYD*).

Options for Adjusting Naturalized Streamflows

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

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

Option 1: No negative incremental flow adjustments. (*ADJINC* = 0 or 1)

Option 2: Downstream negative incremental flow adjustments. (*ADJINC* = 2)

Option 3: Upstream negative incremental flow adjustments are applied at all control points. (*ADJINC* = 3)

Option -3: Variation of Option 3 in which control points with synthesized flows are omitted. Otherwise, Options -3 and 3 are the same. (*ADJINC* =-3)

Option 4: As each water right is considered, upstream negative incremental flow adjustments are applied at the downstream control points but not at the control point of the right. (*ADJINC* = 4)

Option -4: Variation of Option 4 in which control points with synthesized flows are omitted. Otherwise, Options -4 and 4 are the same. (*ADJINC* =-4)

Option 5: A different approach involving modifications to the computations within the water rights loop. Whereas Options 2, 3, and 4 involve computation of an array of flow adjustments, Option 5 does not.

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

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

Option 1 consists of making no adjustments for negative incremental flows. This is more conservative than Options 3 and 4 from the perspective of placing maximum restrictions on the amount of streamflow available to the water rights. In some cases, this may be the most accurate option. In other cases, it may be overly conservative from the perspective of restricting water availability too much, inappropriately increasing diversion shortages and lowering reservoir storage and unappropriated flows. As previously discussed, use of the channel loss option will reduce or

eliminate the restrictions on water availability associated with negative incremental flows. If the negative incremental flows are due primarily to channel losses and reasonably good values for *CL(cp)* are available, this is more likely to be the best option.

Option 2 is based on downstream negative incremental flow adjustments. Since control points on multiple tributaries are not considered concurrently, there is no guarantee of eliminating all negative incrementals. Options 1 and/or 4 will typically be better than Option 2. Reducing naturalized streamflows by the downstream incremental flow adjustments (Option 2) provides few if any advantages relative to making no adjustments at all (default Option 1). However, there may be circumstances when option 2 might be considered. It is the most conservative option since streamflows are reduced rather than increased or left unaltered. If Option 2 is used in combination with the channel loss option, the loss factors *CL(cp)* are reflected in the computation of downstream negative incremental flow adjustments. The channel loss option is treated as an integral part of Option 2, and these two modeling features may be used in combination.

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

Option 4 involves the same flow adjustments as option 3. However, in considering each water right in turn, the flow adjustment is made available at downstream control points but not at the control point of the right. For example, referring to column 7 of Table 6-2, the available flow of 81 ac-ft at CP-2 is determined as the minimum of the following values.

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

Adjustments are added to the flows at the downstream CP-4 and CP-5 but not at the location (CP-2) of the water right. Thus, negative incrementals occurring downstream do not affect the amount of water available to a right. However, negative incrementals in the reaches upstream of the water right do affect its water availability. Option 4 will be the most realistic assumption in many actual river basin modeling situations.

Option 4 includes the following other special features which are not included in Option 3.

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

- With Option 4, the negative incremental flow adjustments are not applied to regulated flows.

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

The channel loss option may be used in combination with negative incremental adjustment Option 4. However, the negative incremental flow adjustment is a correction for channel losses as well as other factors. Therefore, in the water rights computational loop, in determining water availability for a particular right in a particular month, the channel losses factors $CL(cp)$ and negative incremental flow adjustments are not both applied concurrently. Rather, each is applied individually, and the method providing the greatest water availability is adopted. As previously discussed, the model checks available streamflow at all downstream control points as well as at the control point at which the right is located. At each downstream control point, water availability is determined alternatively (1) using the $CL(cp)$ to cascade back upstream and (2) applying the incremental flow adjustment. The method yielding the highest water availability is selected. Channel losses are identically the same with ADJINC of either -4 or 4. Channel losses are computed for all control points with non-zero $CL(cp)$ either way.

In Example 3 presented in Figure 3-2 and Tables 3-1 and 3-2, if $CL(cp)$ for control points CP-1 and CP-4 are 0.1 and 0.2, respectively, the available flow of 81 ac-ft at CP-2 is determined as the minimum of the following values.

CP-1: 90

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

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

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

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

CP-2: 81

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

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

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

CP-4: 100

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

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

1. The amount of water available to that right is determined based on streamflows at its control point and all downstream control points.

2. Water accounting computations are performed to determine streamflow depletion, reservoir evaporation, storage, diversion, shortage, and the other relevant quantities.

3. Streamflows at downstream control points are adjusted for the effects of the water right.

Option 5 is a modified version of the algorithms for steps 1 and 2 above. Incremental flows are not actually computed, and there is no negative flow adjustment array developed prior to the simulation like the other options.

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

Comparison of Options 1, 4, and 5

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

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

- Option 1 is based on the premise that flow at upstream locations must be committed to mitigating excess negative incremental flows at downstream control points prior to meeting downstream water right requirements.

- Option 5 is likewise based on the premise that upstream flow must be used to supply excess negative incremental flow prior to meeting downstream water right requirements. However, this premise is not pertinent if: (1) there is no downstream senior water right that affects upstream water availability or (2) there is a discontinuity of flow between the control point of the downstream senior right and the upstream control point for which water availability is being determined.

- Option 4 is based on the premise that negative incremental flows at downstream control points do not affect water availability at an upstream control point. Flows have to be passed to meet water right requirements at downstream control points, adjusted by C_L channel loss factors. However, water availability at an upstream control point is not reduced for negative incremental flows assigned to other control points located downstream of it.

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

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

- With C_L=0.5 for CP2, a senior streamflow depletion of 80 at CP1 would reduce the flow at CP3 from 40 to zero. A CP1 depletion of 50 would reduce the CP3 flow to 15.

- The maximum amount of water available at CP3 is 40.

- A senior right of up to 40 at CP3 will be met without shortage.

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

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

CP1: 100

↓

CP2: 110

↓

CP3: 40

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

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

computed as follows

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

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

<div align="center">

CP1: 100

↓

CP2: 110

↓

CP3: 0

</div>

<div align="center">Amount of Water Available to a Water Right WR1 at Upstream CP1</div>

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

<div align="center">computed as follows</div>

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

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

<div align="center">

CP1: 100

↓

CP2: 110

↓

CP3: 120

↓

</div>

CP4: 10

↓

CP5: 130

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

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

computed as follows

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

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

Amount of Water Available to a Right WR1 at Upstream CP1

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

computed as follows

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

Selection of a Negative Incremental Flow Option

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

1. permanent channel losses over and above those modeled by the channel loss coefficients

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

3. timing effects of the runoff from a rainfall event reaching an upstream control point in a particular month but reaching a downstream control point early the next month

4. errors and lack of precision in stream flow measurements at the gages and in computations to convert gaged flows to naturalized flows

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

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

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

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

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

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

- Option 2 is similar to the approach mentioned below involving adjustments with spreadsheet computations to remove the negative incremental flows prior to applying *WRAP*. Option 2 is useful for sensitivity studies but would seldom, if ever, be adopted for a final simulation.

- Option 3 is the opposite extreme to Option 1. Option 3 provides high estimates of water availability.   Negative incremental flows have no effect in regard to reducing water availability. Option 3 is useful for sensitivity studies but would seldom, if ever, be adopted for a final simulation.

- Option 4 is probably generally the optimal option for most situations.

- Option 5 relates best to situations characterized by both of the following conditions: (1) The dominant cause of negative incremental flows is permanent channel losses not modeled by the channel loss factors. (2) The water rights system requires that upstream junior water users curtail their use to allow pass-by flows to mitigate downstream channel losses in addition to meeting downstream senior water right diversion, instream flow, and storage amounts. Option 1 is also applicable in these situations, but Option 5 is less overly conservative than Option 1.

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

CHAPTER 4
WATER RIGHTS FEATURES

A *WRAP-SIM* simulation involves combining

sequences of naturalized streamflows and reservoir net evaporation-precipitation rates representing river basin hydrology, as discussed in the preceding Chapter 3,

with

water rights information representing the manner in which water resources are managed and used, as discussed in the present Chapter 4.

This chapter describes capabilities provided by *WRAP-SIM* for modeling a water management/use system consisting of:

- reservoir projects operated to regulate and conserve streamflow, off-channel storage reservoirs, pumping/conveyance facilities, and hydroelectric power plants
- requirements specified in water right permits
- requirements specified in water supply and hydropower contracts and other agreements
- system operating policies and rules
- water use characteristics and practices

In *WRAP* terminology, water resources management and use requirements, policies, practices, and facilities are described in terms of water rights.

Water Rights

In *WRAP*, a water right is a set of water management and use requirements associated with either a water right *WR* record or an instream flow *IF* record. *UC*, *DI*, *IS*, *IP*, *RF*, *WS*, *OR*, *SO*, *TS*, *ML*, and *SD* records are associated with specific *WR* or *IF* records and provide additional information regarding water management and use specifications. Water supply diversion and hydroelectric energy generation are specified as *WR* record rights. Instream flow requirements are specified as *IF* record rights. Rights to refill reservoir storage capacity specified on a *WS* record may be associated with either a *WR* record or *IF* record right. The number of water rights (variable *NWRTS*) counted by *WRAP-SIM* is simply the number of *WR* and *IF* records included in the input file. Thus, the total number of rights counted by the model (number of *WR* and *IF* records) typically does not correspond to the number of actual water right permits.

A key aspect of applying *WRAP* is the exercise of ingenuity in combining water right *WR*, instream flow *IF*, and supporting input records to model a particular water management situation. The model provides considerable flexibility in specifying water management and use requirements. An actual water right permit may be represented by any number of *model water rights*. A single appropriator holding a single water right permit may have several model rights representing different components or features of the water right permit. For example, a water right that includes three different uses, such as municipal, industrial, and irrigation, would be treated as three separate *WR* record rights, since the monthly water use distribution factors are different for the various uses. A 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, a diversion right with zero storage capacity and a storage right with a zero diversion. Also, in certain applications, several actual permitted water rights may be combined and inputted to the model as a single aggregate water right. Multiple rights may be associated with a single reservoir. Likewise, multiple reservoirs may be associated with a single right.

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

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

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

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

Water Right Priorities

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

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

Priorities are integer numbers specified for each *WR* record and *IF* record water right, which are either (1) entered individually on each *WR* and *IF* record, (2) assigned internally by the natural priority option, or (3) specified for water use type groups on *UC* records. Either way, each *WR* and *IF* record water right is assigned an integer number. Smaller numbers mean higher priority, rank, or seniority. If two or more water rights have the same priority number, they are ranked in the same sequence as their *WR* or *IF* records are entered in the input file.

Three alternative methods are provided for specifying priority numbers in *WRAP-SIM*.

1. Priority numbers are entered in field 5 of the *WR* and *IF* records. A blank field 5 is read as a priority number of zero.

2. The natural upstream-to-downstream priority option consists of meeting water right requirements in upstream to downstream order instead of in accordance with the priority system. The natural flow priority option activated by an entry in field 11 of the *JD* record supercedes the priority numbers entered on the *WR/IF* records.

3. Factors entered in fields 9 and 10 of a use coefficient *UC* record replace or modify the priority numbers for all *WR* and *IF* records having the same water use type identifier as the *UC* record.

Field 5 of the *WR* and *IF* records allow each water right to have its own unique priority number. Field 11 of the *JD* record replaces the W*R/IF* record priority numbers with a set of priority numbers that rank the rights in upstream to downstream order. Fields 9 and 10 of the *UC* records allow the priorities entered on the *WR/IF* or *JD* records associated with specified types of water use (field 4 of *WR/IF* record and field 2 of *UC* record) to be replaced or modified.

Natural Upstream-to-Downstream Priority Option

　　　WR/IF record priorities provide capabilities for simulating water management subject to a water rights permit system. Conversely, the natural priority option provides the capability to simulate water management in a river basin without a water rights permit system. Water availability for each water user is affected by other water users located upstream but not by those downstream.

　　　Water right priority numbers assigned to each right on its *WR* or *IF* record allow priorities to be set either without or with regard to spatial location. Alternatively, the natural flow option activated by the *JD* record internally assigns priority numbers to water rights based on the location of their control points. The control points are automatically assigned integer priority numbers starting with 100 and increasing in increments of 100 following the criterion that the integer assigned to any control point is smaller than the number assigned to any other control point located downstream of it. For control points on parallel tributaries, those listed in the input file first are considered first in the algorithm and get the smaller priority number. Each water right is then assigned the number associated with its control point. For multiple rights at the same control point, each right is assigned a unique integer in increments of one. For example, four water rights at a control point with priority number 800 will be assigned priority numbers 800, 801, 802, 803 based upon the relative priorities on their *WR/IF* records. Thus, the algorithm works for up to 100 rights at the same control point. The natural flow option uses the priorities on the *WR/IF* records only to assign relative priorities among multiple rights at the same control point. Otherwise, the *WR/IF* priorities are ignored and water right priorities are assigned in upstream to downstream order.

Priorities by Type of Water Use Option

　　　Water use types are defined by the model-user to fit the particular modeling application. Water use types serve two primary purposes: (1) specifying coefficients for distributing annual use targets over the 12 months of the year and (2) specifying priorities for groups of rights. Examples of possible water use types include municipal, various types of industrial, various types of agricultural, mining, or any other categories of interest. Each water right type is represented by a pair of water use coefficient *UC* records. Field 4 of the *WR* and *IF* records provides a water use identifier that connects the right with a pair of *UC* records.

　　　For each pair of *UC* records, entering the word *YES* in fields 9, 10, and 11 of the first *UC* record activates the following variables entered in the corresponding fields 9, 10, and 11 of the second *UC* record.

field 9	USEP	integer priority number that overrides the *WR/IF* record field 5
field 10	USEM	factor by which the priority numbers in *WR/IF* record field 5 are multiplied
field 11	USEFAC	factor by which the permitted amounts in field 3 of the WR/IF records are multiplied

These factors are applied to all rights that have the pertinent use type identifier in field 4 of the *WR* or *IF* record. As an example of applying this feature, alternative simulation runs might be performed representing alternative municipal water right scenarios. The effects of making municipal rights senior to all other rights might be of interest. By entering 0.1, 0.01, or some other fraction for *USEM* in field 10, the priority numbers for all municipal rights are multiplied by that

factor, making them smaller and thus senior to all other rights. Likewise, an alternative model run examining the effects of a 20 percent reduction in municipal water use could be made with *USEFAC* in field 11 set equal to 0.80.

Specifying Demands and Rules for Meeting the Demands

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

Table 4-1 provides a categorization of the different types and features of water rights. The input records used to activate the various features are also shown. In *WRAP* terminology, a water right is a water management scheme described by the information entered on either a *WR* record or *IF* record along with supporting records tied to the *WR* or *IF* record. *WR* records specify requirements for water supply diversions and return flows or hydroelectric energy generation. *IF* records are used to establish instream flow targets, typically associated with environmental needs. *WR* records are typically used to refill/maintain storage in reservoirs at specified capacities subject to water availability. *IF* records may also include reservoir operations.

A *WR* or *IF* record right, with associated *WS* record, may include refilling storage in one reservoir called its *primary* reservoir. An instream flow, diversion, or hydroelectric energy generation requirement may be met by streamflow and/or releases/withdrawals from the primary reservoir and multiple secondary reservoirs. *Secondary* means the reservoir releases to meet instream flow, diversion or hydropower targets associated with the water right, but its storage is not refilled in association with that particular right. It is refilled by one or more other rights (sets of *WR/WS* or *IF/WS* records). Multiple rights with different priorities may refill storage to different levels in the same reservoir.

Run-of-river diversion or hydroelectric energy generation rights may be modeled by specifying zero active storage capacity. *WR/WS* records may also specify a storage-only right with zero entered for the diversion target.

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

Table 4-1
Classification of Water Right Features

_____

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

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

- *IF* record rights include requirements for instream flows and optionally reservoir storage.

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

- constant annual amount combined with monthly distribution factors   (*WR/IF* 3 & 4, *UC*)

- target series that vary between years as well as between months of the year   (*TS* record)

- specification of diversion and instream flow targets as a function of naturalized/regulated/ unappropriated flows, reservoir storage, and/or streamflow depletions   (*TO* record)

- drought index that allows diversion, instream flow, and hydropower requirements to vary as a function of reservoir storage   (*DI*, *IS*, *IP* records; *IF* record field 8; *WR* record field 10)

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

- secondary backup right that supplies diversion shortages incurred by another right   (*SO* 6)

- streamflow depletions from alternate locations   (*SO* record field 5)

- annual limits on diversions   (*SO* record field 10)

- monthly and annual limits on streamflow depletions   (*SO* record fields 3 & 4; *ML* record)

- monthly and annual limits on withdrawals from reservoir storage   (*SO* record fields 7 & 8)

- monthly varying limits on reservoir storage capacity   (*MS* record)

- multiple entities sharing storage capacity in the same reservoir   (*EA* record)

- multiple reservoir system operations   (*WS* and *OR* records)

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

Type 1: default standard right which may include: diversion and return flow requirements; refilling storage in one reservoir; and releases from one or multiple reservoirs. Diversion requirements are met from reservoir storage only if sufficient streamflow is not available.

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

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

Type 4: diversion target is specified as a function of reservoir storage and naturalized flow

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

Type 6: hydropower right, same as type 3 except a hydroelectric energy generation requirement is specified instead of a diversion requirement

Type 7: flow is discharged into the stream. Used mainly for prioritizing return flows

_____

In addition to the features listed in Table 4-1, a watershed flow option for distributing naturalized flows may be activated by the *SO* record. The watershed flow option is described in Chapter 3 along with the other flow distribution methods. It is different than the other methods in regard to being associated with a water right (*WR* record) rather than a control point (*CP* record).

Water management and use requirements are based on meeting:

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

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

The organization of the *WRAP-SIM* simulation algorithms is outlined by Figure 2-1 and the accompanying discussion in Chapter 2. In a given month, in considering each individual right in priority order in the water rights computation loop, the following tasks are performed by the model for each right in turn.

Task 1: The amount of streamflow available to the right is determined.

Task 2: The diversion, instream flow, or hydropower target for the month is set.

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

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

The following section outlines the overall system for setting diversion, instream flow, and hydropower demands in the model (Task 2 above). Features for modeling operating rules for meeting the demands (Task 3 above) are then described. The last sections of this chapter focus specifically on the details of (1) reservoir storage and reservoir system operations, (2) water supply diversions and return flows, (3) hydroelectric energy generation, and (4) environmental instream flow requirements.

Setting Diversion, Instream Flow, and Hydropower Targets

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

Water use requirements may be specified by any one individual option in *WRAP-SIM*, or alternatively, requirements may be computed within the model by combining multiple optional features. For most typical water rights, targets are defined by simply entering a permitted annual

amount on a *WR* or *IF* record and monthly distribution factors on *UC* records. However, ingenuity may be applied to combine several options to model complex water management situations.

In a given month of the simulation, as the water rights are considered in turn in priority order, *WRAP-SIM* builds monthly diversion, instream flow, or hydroelectric energy targets in sequential steps as outlined below. In the following step-by-step modeling scheme, if multiple options (steps) are used, *WRAP-SIM* combines the target determined with an option with the preceding intermediate target by alternatively either (a) adopting the maximum or minimum or (b) adding the two targets. Embedded within the other sequentially ordered *WR/IF/UC-DI/IS/IP-TO-TS* record steps, step 3 below may also be a series of target building steps with each step being governed by a separate *TO* record.

1. The model combines the annual diversion, hydroelectric energy, or instream flow requirement amount entered in the *WR* or *IF* record with monthly distribution coefficients from *UC* records to obtain a target for each of the 12 months of the year. *UC* records are not required if the monthly target is constant over the year.

2. The backup option activated by the *SO* record allows a water right to serve as a supplemental backup right for another right. Diversion shortages incurred by the preceding right are added to the diversion target of the backup right. The shortage may be added at this step or as step 8 below as specified by the *SO* record.

3. The optional drought index defined by a set of *DI/IS/IP* records modifies the target as a function of the storage content of specified reservoirs. The drought index may be applied here as step 3 or as step 6 below. The location of the drought index adjustment in the computational sequence is specified with the *DINDEX* entry on the *IF* or *WR* record.

4. *WRAP-SIM* uses several variables entered on one or multiple *TO* records to build diversion and instream flow targets. Targets may be a function of naturalized, regulated, or unappropriated streamflow multiplied by a factor. The target may also be set based on reservoir storage or streamflow depletions incurred by other water rights, which may also be multiplied by a factor. Upper and lower bounds on the target may be applied at various points in the target building routine.

    Several *TO* records may be used to build a target step-by-step. The first *TO* record results in a target to be combined with the target determined in steps 1 and 2 above. Each subsequent *TO* record results in another target to be combined with the preceding cumulative target. The two intermediate targets are combined in each step by either (a) selecting either the maximum or minimum or (b) adding them. The target developed in this manner may be a function of the summation of naturalized, regulated, and/or unappropriated streamflow at multiple control point locations, streamflows at various individual locations, reservoir storage, streamflow depletions by other water rights, and/or user specified lower and upper bounds. Flexibility is provided for combining these features as needed to model each particular application.

5. A time series of monthly diversion, hydroelectric energy, or instream flow targets for each month of the hydrologic period-of-analysis may be entered on *TS* records. The *TS* record

may be the only option used for a particular water right, or *TS* record targets may be combined with the other options. Either (a) the greater or lesser or (b) the summation or product of the steps 1-3 versus step 4 values for a particular month is adopted depending on the value for *TSL* entered in the second field of the *TS* record for the first year.

6. A drought index defined by a set of *DI/IS/IP* records modifies the target determined above as a function of the storage content of specified reservoirs. The drought index may be applied at this step in the sequence or as step 3 above.

7. The target may be constrained by upper and lower limits entered on a *TO* record.

8. The backup option activated by the *SO* record may be applied as either steps 2 or 8. The backup right's own target is first determined as outlined above, and then the other right's shortage is added.

The options outlined above are applied in sequential order within *WRAP-SIM* to set targets. Other entrees on a *SO* record may limit the amount of water available to a water right. Water availability for a right is limited by monthly or cumulative annual limits on (1) streamflow depletions and (2) the amount of water that may be withdraw from reservoir storage. An annual diversion limit may be placed on the total water diverted by a right each year.

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

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

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

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

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

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

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

```
IF   CP1                      1985
TO     3    0.25                                    CP2                  CONT
```

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

```
TO     3     .25      ADD                            CP3                  CONT
```

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

```
TO     1    CP1       MIN     100.     500.
```

The target is the minimum of 300 or (1.0)(635)=635 which is 300 ac-ft.
The target is the maximum of 300 or the lower limit 100 which is 300 ac-ft
The target is the minimum of 300 or upper limit of 500 which is 300 ac-ft.

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

_____

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

The purpose of the target series *TS* record option is to provide flexibility for diversion, instream flow, or hydropower targets to be developed outside of the model and entered as input. The targets entered on *TS* records may be determined by various means independently of *WRAP-*

SIM or perhaps from previous simulations performed with the model. The *TS* record targets may be the only requirements specified for a particular water right or alternatively may be integrated with the other options. Targets from *TS* records are integrated into the sequential step-by-step WRAP-SIM target building scheme as Step 5 as previously outlined. *TS* records may be used to modify targets computed within the model with other options. Targets may be arithmetically manipulated by adding, subtracting, or multiplying numbers from *TS* records.

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

Drought or Storage Index

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

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

The program is dimensioned for 100 drought indices that are assigned integer identifiers (1, 2, 3, 4, ... , 100) in the sequential order that the *DI/IS/IP* records for each index are entered in the input file. Entering one of these integer identifiers in field 8 of an *IF* record or field 10 of a *WR* record connects a water right to a drought index. Any number of water rights can be assigned the same drought index.

Each drought index consists of a drought index reservoirs *DI* record and drought index storage *IS* versus percentage *IP* records. The *DI* record specifies the selection of reservoirs upon which to base the index. Either all of the reservoirs in the model or a selection of up to 12 reservoirs may be specified. The *IS* and *IP* records provide a table of reservoir storage versus percentage. The reservoir storage values on the *IS* record refer to the total storage content of the reservoirs specified by the *DI* record. The corresponding percentage on the *IP* record are factors by which the instream flow, diversion, and/or hydroelectric energy requirements are multiplied.

The inclusion of certain reservoirs in the drought index assigned to particular water rights does not otherwise associate the reservoirs with the water rights. *WS* and *OR* records are connected to *WR* and *IF* records identically the same with or without assigning a drought index to the *WR*

record. Instream flow, diversion, and hydropower generation requirements associated with a water right may be determined as a function of a particular drought index without the *DI* record reservoirs making releases for these requirements or being otherwise associated with the right.

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

1. At the beginning of each month of the simulation, the storage contents of all reservoirs in each of the up to 100 drought indices are summed to obtain a total storage for each drought index. All of the reservoirs in the model or up to 12 reservoirs can be selected for each drought index.

2. Linear interpolation is applied in combining the total storage associated with a particular drought index with the storage versus percentage relationship from the *IS/IP* records to obtain a multiplier factor expressed as a percentage.

3. The percentage converted to a fraction is multiplied by the permitted instream flow, diversion, and/or hydroelectric energy targets for each right assigned to a particular drought index.

4. After adjusting the target instream flow, diversion, and hydropower amounts in the previous step, all computations proceed normally without any other change related to the drought index.

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

River/Reservoir System Operating Rules for Meeting Water Use Requirements

Modeling river/reservoir/use system operations may range from very simple to quite complex. Flexible options are provided to model the rules by which streamflow and reservoir storage is allocated to meet the water use targets described in the preceding section. Table 4-1 outlines the optional water rights features for modeling various complexities or different situations. The preceding section focuses on options for setting targets modeling water supply diversion, environmental instream flow, and hydroelectric energy production requirements (demands, rights, needs). The following discussion describes options to be adopted in various combinations to model the manner in which the river/reservoir system is managed to meet these water use targets.

Secondary Backup Diversion Right

The secondary backup option allows diversion shortages associated with a water right to be supplied by another right called a backup right. The backup option is activated by the *SO* record for

the right providing the backup. This right serves as a backup for the right immediately preceding it in the input file. The diversion shortage computed for the preceding water right is added to the diversion target of the backup right. The computations then proceed normally without any other change related to the backup feature. In each month, the diversion target for the backup right is the diversion shortage of the right being backed up plus the target amount determined by its own *WR/UC* records and target setting options on associated SO/TO/TS/DI records.

The *WR* record for a backup right must be the next *WR* record in the input file after the *WR* record and supporting records for the diversion right that is being backed up. However, any number of *IF* record rights may be placed in between. In identifying the preceding right to be backed-up, intervening *IF* record rights are ignored. Applications do occur in which it is useful to place an *IF* record between a *WR* record and its *WR/SO* record backup right.

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

The backup option with *RETURN* entered may be used in combination with a type 7 right to assign a priority to a return flow that is different than the corresponding diversion right. A *WR* record for a type 7 right along with its *SO* record may be placed behind the *WR* and supporting records for a more senior diversion right. The diversion shortage for the first right will be applied in computing the amount *AMTRF* that the second right (type 7 right) returns to the stream as follows:

$$AMTRF_{type\,7\,right} = T_{type\,7\,right} - \left(S_{previous\,right}\right)\left(RFAC_{type\,7\,right}\right)$$

where the target amount *T* for the type 7 right is computed as normal and then adjusted for the shortage *S* from the previous right.

Streamflow Depletions from Multiple Locations

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

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

A typical application of this feature would be a storage reservoir located on a small tributary that is filled by pumping water from a nearby major river as well as the inflows from its own watershed. A *WR/WS/SO* record set allows the reservoir to be refilled from inflows from

the small stream on which it is located. In months in which these inflows are insufficient to fill the reservoir to capacity, a second *WR/WS/SO* record set with an alternate control point allows the reservoir to pump water from the other stream.

Limits on Diversions and Streamflow Depletions

SO record variables *MRW* and *ARW* are limits on monthly and annual withdrawals from reservoir storage. An annual diversion limit *ADL* may also be entered on the SO record. Starting in the first month of each year, the model maintains a record of the total cumulative diversions and the amount of the diversions that came from reservoir storage that year associated with the specified water right. Upon reaching a specified limit, no more water is available to the diversion right until the beginning of the next year.

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

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

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

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

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

If one or more *WS* record reservoirs are connected to a *IF* record, the water right type controlling reservoir operation is specified in field 6 of the *IF* record. Types 1, 2 and 4 of the type 1-7 water right categorization scheme are also applicable to a *IF* record right if and only if it has reservoir storage specified by at least one attached *WS* record. The types 2 and 4 features are applicable only to operation of these reservoirs to meet the instream flow requirement. In general, all junior rights must pass inflows through their reservoirs to meet downstream instream flow requirements. Using a *WS* record to assign reservoir storage to a *IF* record right and using *IF* record field 6 to specify a type are relevant only if releases from storage is required, in addition to passing reservoir inflows, to meet instream flow requirements.

Table 4-2
Water Right Types 1-6

River/Reservoir System Operation	Water Right Type (Field 6 of *WR* Record)					
	1	2	3	4	5 or -1	6 or -3
water supply diversion from streamflow	yes	yes	-	yes	-	-
hydroelectric power generation	-	-	-	-	yes	yes
releases from one or multiple reservoirs	yes	yes	yes	yes	yes	yes
refill storage in one reservoir	yes	-	-	-	yes	-
diversion requirements specified as a function of reservoir storage and naturalized streamflows	-	-	-	yes	-	-

Type 1 right.- Most water rights in a typical river basin will likely be represented as type 1 rights. A type 1 right allows a diversion to be met from streamflow depletions and/or storage in one or more reservoirs. A diversion requirement is met first from streamflow, if available, and then from reservoir storage if streamflow is not available. One reservoir can be refilled from streamflow depletions or releases from other reservoirs in the system. The one reservoir that 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. Releases or withdrawals can be made from a maximum of 20 reservoirs. A storage-only right may simply refill storage in the one reservoir, having a diversion requirement of zero. A run-of-river diversion right can be represented as a type 1 or type 2 right with zero active reservoir storage capacity.

Type 2 right.- A type 2 right is identical to a type 1 right except that reservoir storage is not refilled. Reservoirs may be used along with streamflow to meet diversion requirements, but other rights are used to refill storage. A type 2 right could be mimicked by a type 1 right with an extra reservoir with zero storage capacity.

Type 3 right.- A type 3 right is identical to a type 2 right except the diversion target can be met only by releases or withdrawals from reservoir storage. For example, a diversion could be met by releases from one or more upstream reservoirs without allowing diversion of unregulated 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.

Type 4 right.- A type 4 right allows a diversion target to be specified as a function of reservoir system storage and naturalized streamflow. Thus, certain water demands can be partially or completely curtailed as reservoir storage falls below specified levels. Input data includes a table entered on *SD* records of diversion amount versus total storage in the reservoirs included in the system. The annual water right diversion target with associated monthly water use distribution factors are also input in the same way as for the other water right types. For a given month, the permitted diversion target is computed as the minimum of the values determined (1) by linear interpolation of the diversion versus storage table and (2) from the permitted annual diversion and monthly use factors. An optional feature is also included in the model that limits releases from reservoirs to a user-specified percentage of the naturalized streamflow at the diversion location.

Alternatively, a drought index may be used to specify releases as a function of reservoir storage. The drought index is more generalized than a type 4 right in that the reservoirs included in a drought index may be but are not necessarily operated to meet the requirements of water rights assigned to the drought index. The type 4 feature was included in early versions of the model. The drought index option was added to the model later and essentially supercedes the type 4 option.

Type 5 right.- A hydropower right is identical to a type 1 right except a hydroelectric energy requirement is specified rather than a diversion. A 5 or alternatively a -1 is entered in field 6 of the *WR* record for a hydroelectric power right. A run-of-river hydropower right can be represented as a type 5 right with one reservoir with inactive but no active storage capacity.

Type 6 right.- A type 6 right is identical to a type 5 right except the hydroelectric energy requirement can be met only by releases reservoir storage. A type 6 hydropower right is analogous to a type 3 diversion right. A 6 or -3 is entered in field 6 of the *WR* record.

Type 7 right.- The primary reason for the type 7 right to allow return flows to be assigned priorities that are different than the corresponding diversions. Adding a *WR* record with a type 7 right and a *SO* record with the *RETURN* option along with the *WR* record and other supporting records for a diversion right will reproduce exactly the same simulation results obtained handling return flows in a conventional manner if the priorities are the same. However, the new approach allows the return flows to be placed elsewhere in the priority loop. This allows control over which rights get first access to the return flows.

With a type 7 right, the annual amount *AMT* entered in *WR* record field 3 is discharged into the stream. The stream inflow amounts resulting from type 7 rights are found in the simulation results as return flows. A type 7 right may model a return flow or other situations involving discharge of water into the stream system within the water rights priority computation loop. The target amount is computed for a type 7 right just like any other type of right. The *WR* record annual amount is converted to monthly values by *UC* record factors and may be adjusted by options specified on *SO*, *TO*, *TS*, and *DI* records. The difference is that a type 7 right is not a diversion from the stream, but rather an inflow to the stream. After the monthly amount is determined just like a diversion target, it is then multiplied by the return flow factor *RFAC* from *WR* field 8 and treated computationally as a return flow. *RFAC* is assigned a default of 1.0 if the *RFAC* field is blank. All return flow options are valid, except monthly return factors (*RF* records) can not be used. Water availability computations are not relevant and are not performed for a type 7 right. The flow is simply entered into the stream system; it is not taken from streamflow, reservoir storage, or any other source.

A water right can be associated with up to 20 reservoirs. A *WS* record for each reservoir must follow the *WR* record. Only one reservoir, called the primary reservoir, is allowed to refill storage with that particular right. The water right diversion and primary reservoir must be located at the same control point. Types 1 and 5 rights are the only water rights allowed to refill storage. A type 1 right or hydropower right may have either zero or one primary reservoir and up to 20 secondary reservoirs. The primary reservoir must be cited on the *WS* record immediately following the *WR* record. All reservoirs on the second and subsequent *WS* records are termed secondary reservoirs and can only make releases for the water right, not be refilled by it. All reservoirs associated with type 2, 3, or 4 rights are classified as secondary reservoirs. These reservoirs are refilled by other rights.

Water Right Types in the WRAP-SIM Simulation

The water right type specified on the *WR* record guides the computations within the *WRAP-SIM* water rights loop. The type specification primarily affects the determination of the target requirement for the right and the manner in which the requirement is to be met. The available streamflow is calculated the same regardless of water right type, except hydropower rights are not subject to instream flow requirements. 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. A right is allowed to refill storage only in its primary reservoir, and only up to the storage capacity of the right. A streamflow depletion is then made to meet the target. If the available streamflow is greater than the target, the target streamflow depletion is taken 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, the additional amount is released from reservoir storage.

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

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

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

Diversion requirements for type 4 rights are calculated as a function of several variables. The diversion target is determined as the minimum of a fixed (storage-independent) target and the value determined from linear interpolation of the storage versus diversion table input for the right. The fixed target is the permitted annual diversion multiplied by a monthly distribution factor, as for the other water right types. If no limit on reservoir releases is desired, the required amount is met from streamflow depletions 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 control point of the water right.

Reservoir Storage Capacity

Reservoir storage capacity is provided on the *WS* record associated with a water right *WR* or instream flow *IF* record. Multiple 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's priority, assuming the reservoir has been drawn down in previous months and streamflow is now available for refilling. In addition to specifying a total conservation storage capacity, an inactive pool capacity may also be designated on the *WS* record. In the simulation computations, no releases are made from the inactive pool. The storage level is allowed to fall below the top of inactive pool only due to evaporation. Multiple reservoirs may also be associated with a single water right. However, a right may include a storage capacity to be refilled in only one reservoir, called its *primary* reservoir. Secondary reservoirs supply water use requirements but are not refilled by the right.

Storage Capacity Versus Surface Area and Elevation Relationships

A storage volume versus water surface area relationship is provided as input for each reservoir for use in the net evaporation-precipitation computations. The net evaporation-precipitation volume for a given month is the computed average water surface area during the month times the appropriate net evaporation rate. Two optional formats are provided for inputting a reservoir storage volume versus surface area relationship. A table of storage volume versus surface area can be inputted on *SV/SA* records. The model applies linear interpolation to the table to determine the area corresponding to a computed storage volume. Alternatively, values of the coefficients *a*, *b*, and *c* can be provided on the *WS* record for use in the following equation incorporated in the model:

$$A = aS^b + c \qquad\qquad (4\text{-}1)$$

where *S* and *A* denote storage volume and area. An elevation versus storage volume table is provided on *PE/PV* records for any reservoir associated with hydropower for use in determining head.

Typically, storage volume versus surface area tables are provided on *SV/SA* records for major reservoirs. These data are usually readily available for large reservoirs. A generic set of coefficients (*a*, *b*, *c*) for Equation 4-1 may be developed from data available for a few representative small reservoirs and then applied to numerous smaller reservoirs for which storage-area data are lacking.

Monthly Varying Limits on Storage Capacity

The monthly varying storage capacity option is motivated primarily by seasonal reallocations of storage capacity between flood control and water supply in multiple-purpose reservoirs. Seasonal rule curve operating rules consist of varying the top-of-conservation pool or other designated pool levels with season of the year. Probably the most common use of seasonal rule curve operations is in allocating storage capacity in multiple-purpose reservoirs between flood control and conservation pools, based on seasonally varying characteristics of water supply and flood risk. The flood control pool consists of storage capacity above the designated top of conservation pool elevation that is keep empty except during and following major flood events. The bottom of the flood control pool coincides with the top of the conservation pool. A seasonal rule curve consists of varying the specified top of conservation pool elevation over the year.

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

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

1. Each month, prior to the water rights computation loop, the beginning-of-period storage content of each reservoir is limited to the capacity specified on the *MS* records. If the end-of-period storage content from the previous month exceeds the capacity limit, the excess water in storage is released back to streamflow. This spill is treated identical to the inflows entered on *CI* records. The streamflow at the control point of the water right is increased by the amount of the spill. The streamflow at all downstream control points is increased by the amount of the spill adjusted for channel losses.

2. As reservoir storage is refilled in the water rights loop, the end-of-period storage content is constrained to not exceed the specified monthly varying storage limit.

Optional Beginning Reservoir Storage Content

By default, all reservoirs are assumed to be full to their maximum storage capacity at the beginning of the simulation. However, a less than capacity beginning storage content for any reservoir may be specified on its *WS* record. If not specified otherwise, reservoirs start the simulation full.

Multiple-Right and Multiple-Reservoir Systems

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

- previously discussed water rights features associated with *WR* and *IF* records and attached *WS*, *SO*, *TO*, *TS*, and *ML* records including the river/reservoir system operating rules specified by categorizing a right as type 1, 2, 3, 4, 5, or 6 (*WR/IF* record field 6) and the various supplemental options specified on the other records.

- previously discussed drought indices allowing diversion, instream flow, and hydropower requirements to be specified as a function of reservoir storage content (*DI/IS/IP* records)

- previously discussed monthly varying limits on storage capacity (*MS* records)

- multiple water rights with storage in the same reservoir discussed next (*EA* records)

- multiple reservoir system operating rules discussed next (*OR* records)

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

A *WRAP* water right may include:

1. maintaining (refilling) the storage in a reservoir

2. meeting diversion, hydropower, or instream flow requirements by diverting or releasing from storage in one or multiple reservoirs.

In constructing a model, these two activities can be viewed as being essentially separate. A particular right may include either, neither, or both. Reservoir storage capacity is provided on the *WS* record associated with a water right. Any number of water rights can be associated with a single reservoir, with each right filling the reservoir to a different storage capacity and/or using the reservoir to meet its water use requirements. *WRAP-SIM* allows releases from multiple reservoirs to meet the one diversion, hydropower, or instream flow target and maintain storage in the one reservoir specified by a single water right. The model is dimensioned to allow a water right to include a maximum of 20 reservoirs. As discussed later, the model includes options for specification of multiple-reservoir/river system operating rules (*OR* record). Multiple reservoirs can each have one or more separate rights to maintain their individual storages. Reservoir system operations may be defined by combining any number of *WR/WS* records and other supporting records.

WRAP-SIM is currently dimensioned for a maximum of 5,000 water rights and 1,500 reservoirs located at up to 5,000 control points. Each reservoir is associated with at least one water right. Each reservoir is assigned a control point. Multiple rights and multiple reservoirs may be

assigned to the same control point. Each water right has access, in priority order, to the streamflow inflows at the control point. Each right may have up to 20 reservoirs (one primary and the others secondary).

As discussed in the preceding section, each reservoir must have one and only one storage volume versus surface area relationship entered either as *SV/SA* records or as coefficients on a *WS* record. Each reservoir associated with hydroelectric power must have one and only one storage volume versus elevation relationship entered as *PV/PE* records. The *MS* record option allows each reservoir to have one (or none), but not more than one, set of 12 monthly storage capacity limits. However, each reservoir may be assigned to any number (up to 5,000) of water rights.

As illustrated by Figure 4-1, a reservoir includes an active pool and inactive pool. The inactive pool capacity specified in *WS* record field 7 is dead storage from which releases or withdrawals cannot be made by that right. In the computations associated with that right, the inactive pool can be drawn down only by evaporation. No evaporation occurs from the inactive pool unless the active pool is empty. Releases and withdrawals to meet the requirements for a particular right are made from the storage above its inactive pool. Different water rights associated with the same reservoir can each have a different inactive pool capacity.
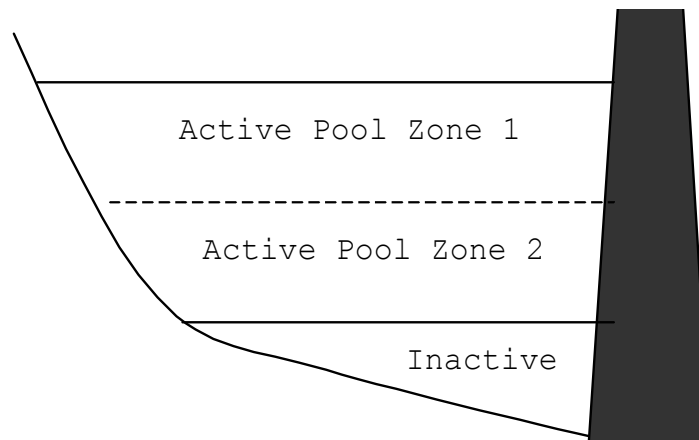
Figure 4-1. **Reservoir Pools and Zones**

Multiple Rights Associated with the Same Reservoir

Any number of water rights can refill storage capacity in the same reservoir and/or make releases from the reservoir to supply diversion, hydropower, or instream flow requirements. The storage capacity entered in field 3 of the *WS* record is the total cumulative capacity to which the reservoir can be refilled under that right's priority, assuming the reservoir has been drawn down in previous months and streamflow is now available for refilling. For reservoirs with multiple rights, the storage capacity specified for each right must equal or exceed the storage capacity specified for more senior rights or else specify no refilling (blank or zero *WS* record field 3). In the water rights priority computational loop, storage capacity can remain the same or be increased but can not be decreased as each more junior right is considered in priority order.

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

Any number of diversion, hydropower generation, or instream flow requirements may be supplied from the same reservoir. A particular right may refill storage, divert/release from storage, or both. A particular reservoir may be the primary reservoir for several rights and a secondary reservoir for other rights. The water use requirements for each right associated with a reservoir is supplied from the total active storage content of the reservoir regardless of how the reservoir is refilled. An inactive storage capacity may be specified for each right, from which releases or diversions can not be made for that right. However, storage capacity associated with a particular reservoir is not otherwise allocated among multiple rights in *WRAP-SIM*. Thus, a junior water right could empty the active storage pool, even though the depleted storage capacity affects water available to a senior right at the same reservoir during the next month. However, as discussed below, the solution to this problem is to model a reservoir with storage capacity shared by multiple water supply entities as multiple separate reservoirs.

Modeling a Single Reservoir as Multiple Reservoirs

Two or more river authorities, water districts, cities, or other entities may share the same reservoir. Each entity owns or contractually controls a specified portion of the storage capacity. If the owners have the same water right priorities, the reservoir is modeled as a single reservoir using the basic *WR* and *WS* record features discussed above. However, if the owners have water rights with different priorities, the multiple-owner reservoir is treated as multiple separate reservoirs located at the same control point. Each component reservoir has its own storage capacity. They have access to streamflow in priority order. The evaporation allocation *EA* record facilitates allocating the net evaporation-precipitation volumes among the otherwise computationally separate reservoirs.

The multiple *computational* reservoirs representing each entity's share of the storage capacity in the single actual reservoir are listed on an evaporation allocation *EA* record along with selection of allocation method As currently dimensioned, up to 50 *EA* records representing 50 actual reservoirs may be included in a data set. Each *EA* record may contain the identifiers of up to 10 *computational* reservoirs representing the multiple storage components of the single actual reservoir.

The following options may be selected for allocating the net evaporation-precipitation volume among the multiple component reservoirs.

1. *Water right priorities*.- As the water rights are considered in priority order, the most senior right with a reservoir on the *EA* record is allocated the net evaporation-precipitation computed prior to considering the other junior rights. Each subsequent water right with a reservoir on the EA record is allocated its incremental additional net evaporation-precipitation.

2. *Proportion to Storage Content*.- The net evaporation-precipitation volume is allocated among the component reservoirs in proportion to their beginning-of-month storage.

3. *User-Specified Factors*.- The total net evaporation-precipitation volume is multiplied by factors entered on an *EF* record. The factors for all the reservoirs would normally sum to 1.0, but this does not necessarily have to be the case.

Total net evaporation-precipitation volume is computed based on the total area determined as a function of total storage content. Total storage determined by summing the contents of the component reservoirs is combined with a storage-area relationship to obtain the water surface area. Although not required by *WRAP-SIM*, component reservoirs will normally share the same storage versus area relationship (*SV/SA* records) in the model. A component reservoir's share of the evaporation-precipitation volume is computed by one of the three methods listed above. Method 1 is based on accumulating storage and evaporation-precipitation from more senior rights only. Methods 2 and 3 consist of multiplying the total net evaporation-precipitation volume by a computed or given factor.

Net evaporation-precipitation volumes are always computed in *WRAP-SIM* based on an average water surface area determined from both end-of-month and beginning-of-month storage. End-of-month storage is a function of evaporation-precipitation, which is a function of end-of-month storage. Thus, an iterative algorithm is required. The evaporation allocation algorithm is integrated into the normal iterative computational procedure for simultaneously determining evaporation-precipitation and end-of-month storage volumes. However, in applying the storage-area relationship to determine water surface area, the best estimate of end-of-month storage at that point in the calculations is used for the allocation algorithm. For any component reservoir for which end-of-month storage has not yet been computed, the end-of-month storage is estimated as the beginning-of-month storage.

Multiple Reservoir System Operations

If two or more reservoirs are associated with a water right, an *OR* record must follow each *WS* 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 location, storage capacity at top of zone 2 (bottom of zone 1) illustrated in Figure 7-1, zones 1 and 2 release priority factors, and specification of gravity flow versus pipeline flow. 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 following discussion of multiple reservoir release rules.

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

The multiple reservoir system release rules may involve interactions with other more senior rights in the river basin. For example, the senior right at control point CP-6 is not part of the four-

reservoir/one-diversion system but impacts the water available to the system. The model maintains an accounting of the amount by which the senior right at CP-6 reduces water availability at the other control points and allows releases to be made from reservoir RES-D, as well as RES-A, RES-B, and RES-C, to mitigate this amount. Therefore, to this limited extent, reservoir RES-D contributes to meeting the permitted system diversion at CP-4 and maintaining storage in the system reservoirs, even though RES-D is not located upstream of CP-4. Likewise, reservoir RES-A can contribute to refilling storage in RES-B and RES-C, and vice versa, in a similar manner.
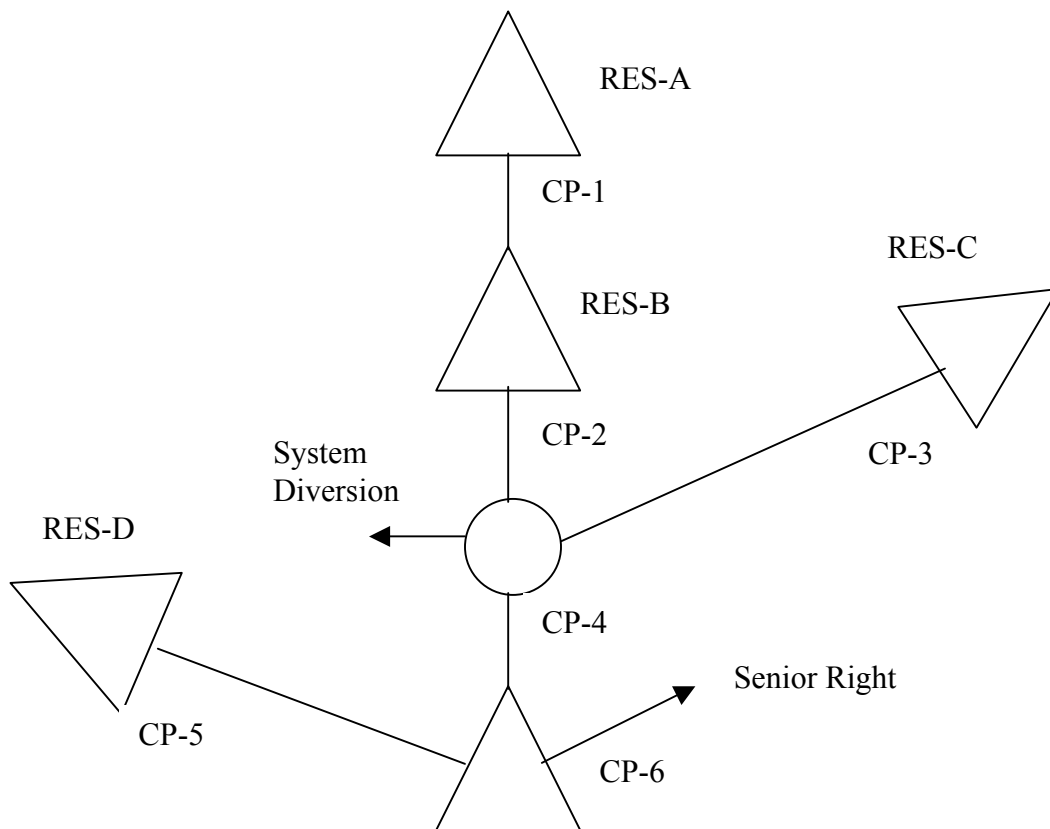
Figure 4-2. **Multiple Reservoir System**

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 4-2 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.

In this example, water is conveyed only by gravity flow in the stream channels. However, *WRAP-SIM* 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 field 6 of the operating rules *OR* record, 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 4-1, 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.

$$rank\ factor\ =\ (weighting\ factor) \left[\frac{storage\ content\ in\ zone}{storage\ capacity\ of\ zone} \right] \tag{4-2}$$

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.

Thus, 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. Field 10 of the *JD* record allows selection between two options regarding the storage to use in the multiple reservoir release decision computations: (1) the beginning-of-period storage or (2) the intermediate end-of-period storage at that point in the computation which is subject to change due to more junior water rights.

Releases for Downstream Senior Rights

As discussed above, reservoirs located upstream of a diversion are assumed to make direct releases to supply the diversion requirement. The pump/pipeline option activated by field 6 of the *OR* record allows diversions from a reservoir to be conveyed to any control point. However, without the pump/pipeline option, 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 requirements as illustrated by the following example.

Referring to Figure 4-2, 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. Naturalized streamflows at 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. 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, 7 ac-ft were passed through the control point to meet the senior right diversion. This amount is the maximum that RES-D may release for the system diversion. Effectively, it is releasing the 7 ac-ft to the senior right, freeing that amount of water for use by the system diversion. Of course, any of the upstream reservoirs RES-A, RES-B, and RES-C may release all of the 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 4 ac-ft for the first system diversion, then it is limited to releasing 3 ac-ft for the second because a total of 7 ac-ft were passed through the control point to the senior water right. *WRAP-SIM* maintains an accounting of depletions at and releases to each control point as well as an accounting at each control point of releases made from downstream reservoirs to determine the downstream releases constraints. Negative incremental inflows may cause inaccuracies in the flow accounting.

Flood Control as a Component of Multiple Purpose Reservoir System 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. However, no special features are included specifically for flood control reservoir operations. To date, the model has not been applied to flood control. Detailed simulation of flood control operations would require a daily or several-hour time step rather than the monthly time interval used in *WRAP*. Present efforts to incorporate sub-monthly (including daily) time step features into *WRAP* will significantly expand capabilities for modeling flood control reservoir operations. However, even with a monthly time step, flood control can be included in an approximate manner in modeling multiple purpose reservoir 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. *IF* records may be used to set instream flow requirements at the allowable nondamaging channel capacities. Flood control storage specified on *WR/WS* records is filled from flows above these levels. Diversion target setting options with 100% return flows may be may be used to empty the flood control pool.

Water Supply Diversions and Return Flows

A monthly water supply diversion target is determined by combining an annual diversion amount from a *WR* record with the appropriate monthly distribution factor from an *UC* record. The water use type on the *WR* record connects the diversion right with the appropriate monthly use coefficients. If a use type is not entered in field 4 of the *IF* or *WR* record, the default of a constant uniform distribution (1/12 of total in each month) is adopted.

As previously discussed, a variety of other options may be employed in setting a diversion target. A series of diversion targets that vary annually as well as monthly may be entered on target series *TS* records. The drought index option (*DI* record) allows diversion targets to be adjusted as a function of storage content in selected reservoirs. A multiplier factor, as a percentage, is determined by combining the beginning-of-month storage with a storage versus multiplier factor relationship defined by *IS/IP* records. The diversion target can also be modified as a function on streamflow, storage, and specified upper and lower limits by options controlled with supplemental options *SO* and target options *TO* records.

Intermediate targets may be computed with the various target setting options. Only, one target and shortage is included in the simulation results recorded for each water right for each period. In the case of adopting multiple options resulting in multiple intermediate targets, a *SO* record entry allows selection of which diversion target and shortage to include in the output file.

In the *WRAP-SIM* simulation, in the water rights priority loop, diversion requirements are satisfied to the extent allowed by available streamflow and reservoir storage. A diversion shortage is declared any time the diversion target can not be fully met. A diversion shortage is computed as the monthly target described in the preceding paragraphs less the computed actual diversion amount as limited by water availability.

As previously discussed, the priority number sets the seniority of the diversion relative to other rights. A diversion requirement may be run-of-river with zero storage. Alternatively, a diversion requirement may be met by streamflow supplemented by releases from one or more reservoirs.

Return Flows

Return flows can represent water discharged back into the stream after use, such as municipal and industrial wastewater treatment plant effluent or irrigation return flows. Return flows can also represent water transported through conveyance facilities such as canals, pipelines, and pumping plants from other control points which may be located any place. The control points of origin and destination of the diversion return flow can be located in different river basins. Intrabasin or interbasin transfers may be simulated in this manner. Alternatively, such transfers of water may also be modeled using the alternate control point (*SO* record), pipeline (*OR* record), or constant inflow (*CI* record) options described elsewhere in this chapter.

Return flows from water uses supplied by groundwater are typically modeled as constant inflows on *CI* records rather than using the *WR* record return flow options described below. The type 7 option on the *WR* record allows the priority of return flows to be controlled.

Hydroelectric power releases through turbines are also treated as return flows using the same options applied to diversions. The default for hydropower is to return 100 percent of the hydropower release at the control point of the hydropower right during the same month as the release. However, the next month option, return to another control point, and the other options available for diversions are computational applied to turbine flows in the same manner.

Return flows are computed in the model as a user-specified fraction of computed actual (rather than target) diversion amounts. A diversion return flow can reenter at any user-specified control point, which could be located downstream or upstream of the diversion location or on a different stream. The diversion amount, return flow factor, and return flow control point location are part of the water right 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.

Return flow specifications provided on the *WR* record for each water right include the return flow factor, the control point location to which flows are returned, and whether return flows occur in the same month as the diversion or the next month. Return flows are computed in *WRAP-SIM* by multiplying a computed diversion by a return flow factor, which may be either a constant specified on the *WR* record for the water right or optionally a set 12 monthly return flow factors specified on *RF* records associated with a specified type of water use.

The variable *RFMETH* entered in field 7 of the *WR* record specifies the return flow method adopted for the water right. The following options are specified by entering a value of 0 (or blank), 1, 2, 3, or 4 for *RFMETH*.

0, 1, blank   A constant return flow factor *RFAC* is specified in field 8 of the *WR* record. If *RFAC* is zero (or blank), the return flow is zero. The return flow occurs in the same month as the diversion.

2   A constant return flow factor *RFAC* is specified in field 8 of the *WR* record. The return flow occurs in the next month after the diversion.

3   An alphanumeric identifier *RFIDWR* is specified in field 8 of the *WR* record which connects the water right to a set of 12 monthly return flow factors input on *RF* records. The return flow occurs in the same month as the diversion.

4   An alphanumeric identifier *RFIDWR* is specified in field 8 of the *WR* record which connects the water right to a set of 12 monthly return flow factors input on *RF* records. The return flow occurs in the next month after the diversion.

Options specified by a *RFMETH* of 3 and 4 require that a set of 12 monthly return flow factors be input on *RF* records. Identifiers input in field 8 of the *WR* records and field 2 of the *RF* records connect the water rights to the appropriate return flow factors. Options 1 and 2 both include a value for *RFAC* on the *WR* record, so *RF* records are not required. If the *RFAC* field is left blank, there is no return flow.

Other Inflows and Outflows

Streamflow adjustments may be specified as either *FA* or *CI* records. Constant inflow *CI* records consist of 12 inflows or outflows, for the 12 months of the year, which are repeated each year. Flow adjustment *FA* records are used to input multiple-year sequences of inflows or outflows, with the monthly flows varying each year. The adjustments from the *FA* or *CI* records are applied by the model in essentially the same manner. The following discussion focuses on *CI* record adjustments but is also pertinent to *FA* record adjustments. As discussed in the *Users Manual*, *WRAP-HYD* provides more flexible options for applying *CI* and *FA* record adjustments, which includes the *WRAP-SIM* methodology discussed below and variations thereof.

The constant inflow/outflow (*CI* record) option allows input of 12 flows, for the 12 months of the year, associated with a specified control point. This option may be used to model:

- return flows not otherwise included in the return flow options, such as return flows from water supply withdrawals from groundwater aquifers

- diversions not otherwise included in the water rights

- channel losses not otherwise included in the channel loss option

- interbasin transfers of water to the control point

- interactions between groundwater and streamflow associated with aquifer pumping

Sets of 12 inflows may be entered for any control points on pairs of constant inflow *CI* records. An outflow is entered as a negative value of inflow. The constant inflows are added to the flows at the control point designated on the *CI* record and at all control points located downstream. If channel loss factors are input on pertinent *CP* records, the *CI* record inflows/outflows are adjusted by channel losses at downstream control points.

Sequences of inflows for each control point provided as input on *IN* records typically consist of naturalized streamflows. The next-period return flow option allows diversion return flows to be added to the naturalized flows for the next month after the diversion. At the beginning of the monthly simulation loop, prior to performing the water allocation computations, *WRAP-SIM* combines the inflows/outflows from the *CI* records with the naturalized flows from the *IN* records and return flows from the previous month. The constant inflows/outflows are added after the optional negative incremental flow adjustments.

A constant monthly outflow may be input as a negative value on a *CI* record. Negative inflows are not allowed to reduce the total streamflow to below zero. If an outflow (negative inflow) is greater than the combined *IN*-record naturalized flow plus return flows from the previous month, the combined total of all three components is set equal to zero. The reduced value of negative inflow at the designated control point is carried downstream. The negative *CI*-record inflow is also restricted from reducing the total flows at the downstream control points to below zero. A *CI*-record outflow (negative inflow) is essentially equivalent to a diversion that is senior to all the water rights on the *WR* and *IF* records.

Hydroelectric Energy

Hydroelectric energy production rights are similar to diversion rights in *WRAP-SIM*. Both hydropower (type 5 and 6) rights and diversion (types 1, 2, 3, and 4) rights are activated with a water right *WR* record. An energy generation target is entered on the *WR* record for a hydropower right. A reservoir storage volume versus elevation table (*PV/PE* records) and constant tailwater elevation (*WS* record) or tailwater elevation versus discharge table (*TE/TQ* records) are input to allow the model to compute head.

For each period of the simulation, the energy production target is met as long as sufficient water and head is available from streamflow and reservoir storage. Power generation may be constrained by an optional turbine discharge capacity and minimum reservoir surface elevation. An energy shortage occurs if sufficient water is not available to meet the user-specified energy requirement. The model also computes a form of secondary or surplus energy. Secondary energy represents additional energy, above the specified energy target, that potentially could be generated by passing reservoir releases for downstream diversions through the turbines. Only reservoir releases for water rights senior to the hydropower right are considered in computing secondary energy. Secondary energy is treated by the model as a *negative* energy shortage. No releases from storage or streamflow depletions are made if previous releases for senior rights are sufficient to meet or exceed the energy requirement.

Input Data for Hydropower Rights

A hydroelectric energy generation right is represented by the following input data:

- control point location [*WR* record field 2]

- annual energy generation target [*WR* record field 3]

- set of 12 monthly energy target distribution factors [*WR* record field 4; *UC* records]

- drought index for varying energy target as a function of reservoir storage [*DI/IS/IP* records]

- optional series of monthly energy generation targets that vary between years [*TS* record]

- priority number [*WR* record field 5]

- water right type [*WR* record field 6]

- active and inactive reservoir storage capacities [*WS* record fields 3 and 7]

- plant efficiency factor [*WS* record field 10]

- optional turbine discharge capacity [*WS* record field 12]

- optional minimum pool elevation [*WS* record field 13]

- constant tailwater elevation [*WS* record field 9] or tailwater rating table [*TE/TQ* records]

- reservoir storage versus water surface elevation table [*PV/PE* records]

- multiple-reservoir system operating rules [*OR* records]

- turbine discharge return flow specifications [*WR* record fields 7, 8, 9]

- Multiplier factor *POWFCT* [*XL* record field 7]

Hydroelectric energy computations are based on the following equations:

$$E = P\,t \qquad\qquad (4\text{-}3)$$

$$P = \gamma Q H e \text{ (unit conversion factors)} \qquad\qquad (4\text{-}4)$$

$$E = \gamma\, Q\, H\, e\, t \text{ (unit conversion factors)} = QHet\,(POWFCT) \qquad (4\text{-}5)$$

where:

E =   energy generated [Watt•hour (W-hr) = 3,600 Newton•meters = 2,650 ft•lbs; megaWatt•hr (MW-hr) = 1,000,000 W-hr = 1,000 kiloWatt•hr (kW-hr)]

P =   power generated [Watt (W) = N•m/second; MW = 1,000,000 W = 1,000 kW; horsepower = 550 ft•lb/s = 0.7457 kW]

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

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

H =   head [feet, meters]

      = mean reservoir water surface elevation for period minus tailwater elevation

e =   plant efficiency [dimensionless]

t =   time period (one month)

POWFCT = power factor used in *WRAP-SIM*

In the model, hydroelectric energy (E) produced is represented as:

$$E = QHet(POWFCT) \qquad\qquad (4\text{-}6)$$

where:

$$POWFCT = \gamma \text{ (unit conversion factors)} \qquad\qquad (4\text{-}7)$$

POWFCT is a multiplier factor that reflects unit conversions and the unit weight of water. Values of *POWFCT* for several alternative sets of units are tabulated in Table 4-3 and may be computed for any other set of units. *WRAP-SIM* uses a default *POWFCT* of 0.0010237 corresponding to the units shown in the last column of Table 4-3. Thus, the default *POWFCT* = 0.0010237 automatically used by *WRAP-SIM* is appropriate if the variables are expressed in the following units: energy (E) in megawatt-hours (MW-hrs), discharge (Q) in acre-feet/month, and head (H) in feet. If other units are adopted, a value for *POWFCT* must be entered in field 7 of the multiplier factor *XL* record.

Table 4-3
Hydropower Factor for Alternative Sets of Units

specific weight γ units for:	9.80 kN/m^3	9.80 kN/m^3	9.80 kN/m^3	62.4 lb/ft^3	62.4 lb/ft^3	62.4 lb/ft^3
volume/period, Q	m^3	1,000 m^3	10^6 m^3	acre•feet	acre•feet	acre•feet
head, H	meters	meters	meters	feet	feet	feet
energy, E	kN•m	kW•hrs	MW•hrs	ft•lbs	kW•hrs	MW•hrs
POWFCT	9.80	2.7222	2.7222	2,718,144	1.0237	0.0010237

The model default of *POWFCT* = 0.0010237 with energy in megaWatt-hours (MW-hrs) is computed as follows for illustrative purposes.

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

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

$$E \;=\; QHet \,(0.0010237)$$

As noted in Table 4-3, the value for *POWFCT* is 2.7222 if the following units are adopted: flow volume for period t in 1,000 cubic meters (10^3 m^3), head in meters (m), and energy in kiloWatt-hours (kW-hrs).

$$E = \left(9.80 \ \frac{\text{kN}}{\text{m}^3}\right)\left(\frac{10^3 \text{m}^3}{\text{month}}\right)(\text{meters})\ (\text{month})\ \left(\frac{\text{hour}}{3{,}600\,\text{s}}\right)$$

$$E \;=\; QHet \,(2.7222)$$

POWFCT values for any other set of units can be determined in a similar manner.

WRAP-SIM Simulation of Hydroelectric Power

Types 5 and 6 hydropower rights are analogous to types 1 and 3 diversion rights. A type 6 right limits energy generation to releases from storage. Type 5 rights allow refilling of reservoir storage. With either type 5 or 6 rights, releases may contribute to downstream flows optionally either the same or next month. The return flow options specified by fields 7-8 (*RFMETHOD, RFAC, RFIDWR, RCP*) of the *WR* record are applied to hydropower releases the same as to diversions. The default is to return 100 percent of the hydropower release at the control point of the hydropower right. Since type 5 and 6 rights are not constrained by instream flow rights, reservoir storage should be refilled with a separate *WR* record that is subject to instream flow requirements.

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.

The *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.

Hydroelectric power production can be included in multiple reservoir system operations. Energy can be generated at a hydroelectric plant using flows from releases from multiple reservoirs. When a non-hydropower water right diversion is met from a primary reservoir and/or secondary reservoirs, the water is released either through the reservoir hydropower turbines or directly from the reservoir pool, not passing through the turbines, depending upon the input specifications (*WS* record field 11). The hydropower release is computed as the additional release amount needed to meet the permitted energy target, considering all releases for more senior rights that pass incidentally through the turbines.

Because the energy produced is a function of both the flow through the turbines and the average head on the turbines, hydropower rights are handled differently than diversion rights in regard to assumptions regarding refilling reservoir storage. The 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 energy requirement 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 streamflow depletions and reservoir releases necessary to just maintain the storage level while meeting the energy requirement. The target streamflow depletion is computed as the additional water that must be passed through the hydropower turbines assuming that the end-of-period storage is either the water right storage capacity or the current storage level, whichever is higher, plus the amount needed to refill storage. The storage used in the computations is the current end-of-period storage for that reservoir. Junior rights associated with that reservoir may increase or decrease the storage amount, changing the energy actually produced at the reservoir. The value output for the energy generated on a reservoir/hydropower record in a *WRAP-SIM* main output file represents the energy produced by the most junior hydropower right of the reservoir. The intermediate values of energy for senior rights are listed in the reservoir/hydropower output file.

The appropriate streamflow depletion and reservoir release are 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 energy requirement.

Instream Flow Requirements

In *WRAP*, an instream flow requirement is a specified target minimum regulated flow rate at a control point location. Several options are available for setting monthly instream flow targets. An annual instream flow target amount from an *IF* record is combined with a set of 12 monthly distribution factors provided on *UC* records (just like diversion rights) to develop monthly regulated flow targets. Optionally, the monthly regulated flow target can be adjusted by multiplying by a drought index factor determined from data entered on *DI/IS/IP* records (again just like diversion rights). Instream flow targets may also be limited to not exceed a specified percentage of naturalized streamflow specified on the *IF* record. The units for instream flow targets are the same as the other flow rate terms in *WRAP*, which are typically in acre-feet/month though other units may also be adopted.

Water allocation routines in *WRAP-SIM* are based on user-assigned priorities for all rights, which include instream flow requirements as well as diversion, storage, and hydroelectric

energy requirements. Instream flow requirements may be assigned to any or all control points. Multiple instream flow requirements with different priorities, thus affecting different diversion and storage rights, may be assigned to the same control point.

Two types of actions may occur in the simulation in order to prevent or minimize failures (shortages) in meeting the instream flow requirements.

1. Constraints placed on the amount of streamflow available to diversion and storage rights, that are junior to an instream flow requirement, may result in these rights being curtailed to minimize shortages in meeting the instream flow target.

2. Reservoir releases may be made specifically to meet instream flow requirements.

In the *WRAP-SIM* water rights computation loop, with or without instream flow requirements, the amount of water available to a right is based on yet unappropriated flows at the control point of the right and at all downstream control points. Instream flow requirements add constraints limiting water availability based on regulated flow targets. Diversion and storage rights that are junior to an instream flow requirement may have the amount of water available to them constrained, thus resulting in curtailment of streamflow depletions for diversions and reservoir storage.

Junior diversion rights are curtailed, and inflows are passed through junior upstream reservoirs to meet an instream flow requirement, regardless of whether or not storage rights (*WS* record) are attached to the instream flow right (*IF* record). However, a reservoir storage *WS* record must follow the *IF* record in the *WRAP-SIM* input file if:

1. releases from storage in one or more reservoirs associated with the instream flow right are to be used to prevent regulated flows from falling below the minimum levels specified by the instream flow targets and/or

2. streamflow depletions are to be made to refill reservoir storage.

Reservoir storage (*WS* and *OR* records) is incorporated with instream flow rights (*IF* records) just the same as with diversion and hydropower rights (*WR* records).

Specification of Instream Flow Requirements

Instream flow requirements are specified in a *WRAP* input file using instream flow *IF*, water use coefficient *UC*, drought index *DI/IS/IP*, supplemental options *OR*, target series *TS*, reservoir storage *WS*, and multiple-reservoir operating rules *OR* records. The *UC, DI/IS/IP, SO, TS, WS*, and *OR* records are used with an *IF* record in the same manner as with the *WR* record. An *IF* record is required for each instream flow requirement. *DI/IS/IP* records are used only if the minimum flow targets fluctuate with reservoir storage. *SO* and *TS* records provide additional flexibility for defining instream flow targets. *WS* and *OR* records are entered only if reservoir storage is used to meet instream flow requirements. Any number of *IF* records may be input for a particular control point, with the next more junior instream flow target replacing the latest more senior target in the priority-based water rights computational loop.

In *WRAP*, a water right consists of either an *IF* or a *WR* record, which may be accompanied by other records providing associated information. The model-user combines one or more *IF* and/or *WR* records along with other records as necessary to model a particular water rights permit. The instream flow *IF* record is similar to the water right *WR* record. In a *WRAP-SIM* input file, *IF* and *WR* records are grouped together in any order. *IF* records may be grouped together and placed either before or after the *WR* records or interspersed between *WR* records. *UC*, *DI/IS/IP*, *SO*, *TS*, *WS*, and *OR* records are associated with *IF* records exactly as with *WR* records.

The instream flow amount *AMT* from the *IF* record is handled differently in the simulation than the diversion amount *AMT* in the same field of the *WR* record. The instream flow amount is a target minimum regulated flow at a control point. Without an instream flow requirement, the amount of water available to each right is based on unappropriated flows. The instream flow target adds another constraint, based on regulated flows, on the amount of water available to all the water rights with priority numbers junior to that of the instream flow requirement.

Setting the Monthly Instream Flow Target

The instream flow target for a month is a minimum limit on the regulated streamflow at a control point. The objective is to maintain a regulated flow equal to or greater than the instream flow target. Instream flow targets are determined step-by-step within *WRAP-SIM* as follows. Many typical situations may be modeled using only step 1. However, the options noted in the other steps provide flexibility to model a wide range of requirements. As previously discussed, all of the following steps are essentially identical for developing either instream flow, diversion, or hydropower targets, except step 3 is not relevant to hydropower.

1. The annual instream flow requirement entered in field 3 of an *IF* record is combined with monthly distribution coefficients from *UC* records to obtain a target for each of the 12 months of the year. *UC* records are not required is the target is constant over the year.
2. An optional drought index defined by a set of *DI/IS/IP* records is used to modify the target determined in step 1 above as a function of reservoir storage.

3. An intermediate target determined in the preceding steps 1 and 2 may be further adjusted or combined with computations specified by one or more target options *TO* records. Options activated by the *TO* record allow a target to be computed as a function of naturalized, regulated, or unappropriated streamflow, reservoir storage, and/or water taken by other water rights. Targets may be set based on whether or not these quantities fall within specified limits or otherwise set as arithmetic functions of these quantities. Either the greater or lesser of intermediate targets computed different ways or their summation for a particular month is adopted depending on the specifications entered in the *TO* record. The option for determining a target as a function of naturalized, regulated, or unappropriated streamflow are designed to be repeated with multiple *TO* records to combine streamflows at multiple locations by addition/subtraction or selecting between the minimum or maximum. Minimum and maximum limits on the target may also be specified.

4. A time series of monthly targets for each month of the hydrologic period-of-analysis may be entered on *TS* records. Instream flow targets entered on *TS* records may be determined

independently of *WRAP-SIM* or through previous simulations with *WRAP-SIM*. The *TS* record option may be used alone or in combination with the other options. If used with other options, targets determined different ways are combined by either addition, subtraction, or multiplication or taking the maximum or minimum as specified by the value for *TSL* entered in the second field of the *TS* record for the first year.

5. A drought index defined by a set of *DI/IS/IP* records modifies the target as a function of reservoir storage. The entry for *DINDEX* on the *IF* record specifies the location in the computational sequence at which the drought index is applied. It may be applied either as step 2 above or to the final target after completion of the *TO* and *TS* record operations.

Types of Instream Flow Computations

The type of computations associated with a particular instream flow requirement is specified as variable *IFFLAG* in field 7 of the *IF* record. The options are as follows.

IFFLAG

0   Shortages in meeting instream flow requirements are computed, but no action is taken to prevent or reduce the instream flow shortages.

1   Junior rights are curtailed as necessary to meet instream flow requirements during a single pass through the water rights loop. The instream flow requirement (minimum regulated flow target) results in a constraint on the amount of water available to all junior rights. In the water rights computational loop, at each right, the intermediate estimate of regulated flow is approximate since the effects of more junior rights have not yet been considered.

2   Junior rights are curtailed as necessary to meet instream flow requirement during a second pass through the water rights loop. The first pass through the water rights loop is used to compute regulated flows and instream flow shortages without limiting the amount of water available for other rights. The second pass is made only if at least one instream flow failure (shortage) occurs during the first pass.

3   Option 3 is the same as Option 1 except reservoir storage is used as necessary to meet instream flow requirements. Option 3 requires that a reservoir storage *WS* record follow immediately behind the *IF* record. The *WS* record may be followed by *OR* records.

4   Option 4 is the same as Option 2 except reservoir storage is used as necessary to meet instream flow requirements. Option 4 requires that a reservoir storage *WS* record follow immediately behind the *IF* record. The *WS* record may be followed by *OR* records.

5   Instream flow requirements are totally ignored. Option 5 allows an instream flow requirement to be ignored in an alternative simulation run without the inconvenience of actually removing the *IF* record.

For purposes of illustrating the *WRAP-SIM* strategy for modeling instream flow requirements, the computations to result from the input records shown below are discussed. Only the portion of the input file relevant to instream flow requirements is shown.

```
various input records of various types
various UC records
UCseason      0         0        0        0        0      0.25
UC          0.5      0.25        0        0        0         0
UC irrig      0         0        0      0.1      0.1       0.3
UC          0.4       0.1        0      0.0      0.0       0.0
other UC records
various other types of records
IF   CP7     6000          19850501        2           IF1
IF   CP15    5200   season19720801         2           IF2
IF   CP7    12000          19910215        2           IF3
IF   CP12    1800          19880601        2           IF4
WR   CP12    7800   irrig19880601                 0.25           WR76
WS   Res21 125000        -1
IF   CP12       0          19880601        2           IF5
IF   CP7     9000          99999999        4           IF6
WS   Res3   50000        -1
    many other records of various types
```

Water is allocated to all *IF* and *WR* rights in turn, in priority order, as the simulation proceeds through the water rights loop for January of the first year. Instream flow requirement *IF2* at control point *CP15*, with a priority date of 1 August 1972 (19720801) is the most senior of the rights shown and therefore the first to be considered. Multiplying the annual instream flow target of 5,200 ac-ft/yr by a January distribution factor of 0.0 results in a January target of zero.

Instream flow requirement *IF1* at control point *CP7*, with a priority of 19850501 (1 May 1985), is considered next. The January instream flow target is 1/12 of 6,000 ac-ft/yr or 500 ac-ft/month. This 500 ac-ft/month regulated flow target serves as a constraint on the amount of water available to water rights with a priority junior to 1 May 1985.

Instream flow requirement *IF3*, with a priority of 19910215 (15 February 1991), raises the instream flow target at control point *CP7* from 500 ac-ft/month, set by *IF1*, to 1,000 ac-ft/month. Thus, all rights with a priority date between 1 May 1985 and 14 February 1991 are subject to an instream flow requirement at *CP7* of 500 ac-ft/month, and those with priority dates of 15 February 1991 or later are subject to an instream flow requirement of 1,000 ac-ft/month.

Rights *IF4*, *WR76*, and *IF5* at control point *CP12* all have a priority of 19880601 (1 June 1988). Multiple rights with the same priority number are considered in the order they are entered in the input file. *IF4* sets an instream flow target of 150 ac-ft/month, which constrains the amount of water available to water right *WR76*. *IF5* resets the instream flow target back to zero. Thus, the 150 ac-ft/month instream flow requirement at *CP12* affects only water right *WR76*.

Instream flow requirement *IF6* changes the minimum regulated flow target at control point *CP7* from 1,000 ac-ft/month, set previously by *IF3*, to 750 ac-ft/month. Since the *IF6*

priority of 99999999 is junior to all other water rights, this target has no affect on the amount of water available to the other rights. If the regulated flow at *CP7* is less than 750 ac-ft/month, releases from reservoir *RES3* will be made to increase it to 750 ac-ft/month, as specified by the *WS* record following the *IF* record for *IF6*.

Instream flow Computations

The instream flow features of *WRAP-SIM* are incorporated in the main program and subroutines *WRAPIN* and *AVALB*. *IF* and *WR* records are read in the same section of *WRAPIN*, which is the subroutine that reads all input data except the hydrology-related records. Subroutine *AVALB* computes the amount of water available to a right based on the unappropriated and regulated flows at the control point of the right and all downstream control points. The regulated flow component of subroutine *AVALB* is designed specifically for modeling instream flow requirements.

The instream flow computations occur within the *WRAP-SIM* water rights loop, which is embedded with the monthly period loop. The original and modified *WRAP* are based on the fundamental concept of allocating the monthly naturalized streamflow (along with storage and return flows carried over from the previous month) to the water rights in priority order. Instream flow (*IF* record) rights have a priority number just like *WR* record rights (diversion, storage, and/or hydropower rights). *IF* and *WR* record rights are all considered in turn in priority order. The total number of rights (variable *NWRTS* in the code) is the total number of both *IF* and *WR* records in the input file.

For each month of the simulation, the instream flow routines perform the following tasks. The relevant options shown in parenthesis are specified by input variable *IFFLAG* in field 8 of the *IF* record.

- *Setting the Instream Flow Target for the Month (Options 0, 1, 2, 3, and 4)*

WRAP-SIM determines the monthly instream flow target following the procedure previously outlined based on information entered on *IF*, *UC*, *DI/IS/IP*, *SO*, and/or *TS* records. An instream flow target is determined the same way as a diversion target. An instream flow target is expressed in the same units as a diversion target, typically in acre-feet/ month though other units could be used.

- *Writing Instream flow Shortages to the Output File (Options 0, 1, 2, 3, and 4)*

The instream flow requirement is a target minimum regulated flow. For a given month, at the completion of the water rights loop, the instream flow target for each *IF* record right is compared with the regulated flows at the appropriate control point to determine whether failures to meet the targets occur and to compute the shortage amounts. A shortage occurs when the regulated flow is less then the instream flow target. The shortage, in ac-ft/month, is the difference between the instream flow target and the regulated flow. The instream flow targets and shortages (variables *IFTARGET(WR)* and *IFSHORT(WR)*) are written to the main *WRAP* output file. Program *TABLES* reads the *WRAP-SIM* output file and builds instream flow shortage tables in the same manner as the other tables are developed.

- *Initial Pass through Water Rights Loop (Options 0, 2, and 4)*

In the initial pass through the water rights computational loop, regulated flow constraints are not placed on the amount of water available to each *WR* record water right. Thus, junior rights are not curtailed to prevent instream flow shortages from occurring. For option 0, computing and writing the instream flow shortages is all that is done; the initial pass through the water rights loop is the only pass.

For options 2 and 4, this is the first of two possible passes through the water rights loop. If one or more failures to meet instream flow targets occur, a second pass through the computational loop is made. If no failures to meet instream flow targets occur in the first pass, there is no second pass; the simulation proceeds to the next month. For options 2 and 4, the first pass through the water rights loop serves the following purposes.

1. A determination is made of whether or not failures to meet instream flow requirements occur if no other diversion and storage rights are curtailed. The second pass through the water rights loop described below occurs only if one or more failures to meet instream flow targets occur in the first pass. This guarantees that junior rights are not unnecessarily curtailed due to instream flow requirements, in those months in which all instream flow requirements can be met without curtailing junior rights.

2. The regulated flows reflecting all the water rights are determined in this first pass. These regulated flows are used in the second pass as a lower limit on the regulated flows used to define water availability. This prevents junior rights from being curtailed more than necessary in those months in which instream flow requirements do limit the amount of water available to junior rights.

- *Second Pass through Water Rights Loop (Options 2 and 4)*

If instream flow shortages occur during the first pass through the water rights loop described above, a second pass is performed. In the second pass, instream flow requirements result in constraints on the amount of water available to all rights that are junior to the instream flow requirements, except hydropower rights. The constraints on water availability result in junior rights being curtailed as necessary to prevent or minimize instream flow shortages.

Within the priority-based water rights loop, an instream flow requirement establishes a minimum regulated flow target at a specified control point that results in a constraint on water availability for junior water rights. The regulated flow is compared with the instream flow target to determine the limit on water availability. The regulated flow constraint is incorporated in subroutine *AVALB* for computing the amount of water available to each right in the priority loop.

Intermediate regulated flows computed during the second pass, with a minimum limit set by the final regulated flows at the completion of the first pass, are combined with the instream flow requirements to determine the constraints on water availability. As each water right is considered in turn, the intermediate estimate of regulated flow reflects only the effects of more senior rights, since the junior rights have not yet been considered in the priority-based water rights loop. However, the algorithm in *WRAP-SIM* limits the regulated flow during the second pass to not drop below the final regulated flow computed at the completion of the first pass.

Any number of instream flow requirements (*IF* records) may be input for a particular control point, with the next more junior *IF* record target replacing the latest more senior target in the priority-based water rights loop. Thus, as each water right is considered in turn based on priority, the only instream flow target at a control point constraining water availability is the last *IF* record target set based on priority. However, this instream flow target may be replaced by a more junior *IF* record instream flow target later in the priority loop.

Hydroelectric power rights are flagged to not be constrained by instream flow requirements, since turbine releases do not diminish regulated flows. For hydropower rights, storage and energy requirements may be entered on separate *WR* records, if necessary, so that the reservoir storage is constrained by instream flow limits on downstream water availability, but the turbine releases are not.

- *Single Pass through Water Rights Loop (Options 1 and 3)*

Options 1 and 3 involve only one pass through the water rights loop. The instream flow requirements result in constraints on the amount of water available to junior water rights. The computations setting limits on water availability are essentially the same as those performed in the second pass for Options 2 and 4 described above. However, as noted above, the intermediate estimates of regulated flow reflects only the effects of more senior rights, since the junior rights have not yet been considered in the priority-based water rights loop. Options 1 and 3 can not incorporate the lower limit on regulated flows adopted in the dual pass approach. Junior rights may be unnecessarily curtailed.

- *Reservoir Storage for Meeting Instream flow Requirements (Options 3 and 4)*

Options 3 and 4 involve using reservoir storage to meet instream flow requirements. Option 3 consists of adding reservoir storage to option 1. Option 4 consists of adding reservoir storage to option 2. A reservoir storage *WS* record must follow the *IF* record for an option 3 or 4 instream flow requirement. Multiple-reservoir operating rules *OR* records may follow the *WS* record as appropriate.

Instream flow shortages are determined in the water rights loop. Whenever the instream flow target exceeds the regulated flow for a given month at a control point, a shortage is computed as the instream flow target minus the regulated flow. For an *IF* record right with reservoir storage (option 3 or 4), the instream flow shortage is mimicked as a diversion right with return flow factor of 1.0. The 100% return flow occurs at the same control point as the dummy diversion (instream flow shortage). Thus, if an instream shortage occurs, a diversion target equal to the shortage is created, and the corresponding return flow factor is assigned a value of 1.0. The *IF* record right is then processed through the water right computations just like a *WR* record right.

Further Discussion of Key Features of the Instream flow Modeling Capabilities

Fundamental concepts reflected in the *WRAP-SIM* options for modeling instream flow requirements are further highlighted as follows.

Regulated Flows and Instream Flow Targets

For a given month, water is allocated to each water right in turn, in priority order, in the water rights computational loop. At the beginning of the water rights loop, the regulated flow at a control point is the summation of:

- the naturalized flows from the *IN* records
- return flows from the previous month if the next-month return flow option is used
- gains or losses from an optional *CI* record

During the water rights allocation computations, the regulated flows are diminished by streamflow depletions for diversions and refilling reservoir storage. The regulated flows may be increased by return flows from diversions from reservoir storage, hydropower releases, or upstream reservoir releases for downstream diversions. The intermediate regulated flows and unappropriated flows in effect, when a particular water right is considered in the priority-based water allocation computation loop, depend upon the effects of the more senior rights that have already been considered.

From the perspective of *WRAP-SIM*, an instream flow requirement is a target regulated flow at a control point. Any number of *IF* records may be associated with a control point, allowing the target minimum regulated flow to change in the priority loop as the various water rights are considered. An actual instream flow requirement is modeled by combining as many *IF* records as necessary.

An instream flow shortage occurs if the regulated flow falls below a minimum flow target. *WRAP-SIM* computes and outputs the monthly instream flow shortages for each *IF* record right.

Actions to Prevent or Reduce Instream flow Shortages

The following two approaches are incorporated in *WRAP* to model regulatory actions in maintaining instream flow requirements.

1. In the water rights loop, as each water right is considered in turn, a first step is to compute the amount of water available to that right. The instream flow target is a constraint on the amount of water available to *WR* record rights that are junior in priority to the *IF* record instream flow target. Reductions in water availability may result in curtailment of streamflow depletions for meeting diversion requirements and refilling reservoir storage associated with these junior rights.

2. An instream flow right (*IF* record) may also have its own reservoir storage (*WS* record). Releases from storage are made as necessary to prevent or minimize the instream flow shortage. The *IF* record right may also include refilling of storage just like a *WR* record right. In the model computations, the instream flow shortage is converted to a dummy diversion with 100% return flow, which is then handled the same as a *WR* record diversion and storage right.

Modeling the effects of instream flow requirements on the numerous other diversion and storage rights in a river basin is complicated by the combination of the following two considerations.

1. Available streamflow is allocated to the water rights based on priorities. Thus, the water rights are considered in priority order in the water rights computation loop.

2. Diversion and storage rights may either increase or decrease the regulated flows at a control point. Diversions and refilling reservoir storage decrease regulated flows at downstream control points. Conversely, regulated flows may be increased by (1) return flows from diversions from either storage or streamflow, (2) hydropower releases, or (3) upstream reservoir releases for downstream diversions.

In the priority-based water rights computational loop, restrictions on water availability due to instream flow requirements may result in shortages in meeting diversion and/or storage requirements that are not necessary. For example, the regulated flows may have dropped below the target level, thus restricting water availability, when a particular diversion right is considered. Thus, the diversion right incurs a shortage. However, more junior rights considered later in the computations may result in return flows from diversions from reservoir storage that raise the regulated flow above the instream flow target.

The approach of performing two passes through the water rights computation loop is designed to address this complication. *IFFLAG* option 1 and the associated option 3 perform the water allocation computations during a single pass through the water rights loops. The instream flow shortages computed by this approach are accurate. However, diversions and refilling of reservoir storage associated with other rights may have been curtailed more than necessary to prevent or reduce instream flow shortages. The dual-pass approach of option 2 and associated option 4 provides protection against erroneously over restricting the amount of water available to other water rights in two regards.

1. In the dual pass approach, the first pass is used to compute regulated flows without allowing instream flow requirements to restrict the amount of water available to junior rights. The second pass occurs only if the first pass results in one or more instream flow shortages. Thus, option 2 guarantees that junior rights are not affected in any month in which instream flow targets are met anyway without restricting the amount of water available to other rights.

2. At completion of the first pass, the regulated flows reflect the effects of all water rights, but the rights are unrestricted by instream flow targets. In option 2, these final first-pass regulated flows are used in the second pass to set a lower limit on regulated flows used in the water availability computations. This prevents junior rights from being curtailed more than necessary in those months in which instream flow requirements do limit the amount of water available to junior rights.

An erroneous instream flow shortage could possibly occur in a situation in which a diversion right actually increased regulated flows in the first pass but is curtailed in the second pass. An example (perhaps the only example) is a diversion occurring downstream of the

instream flow requirement control point made from releases from a reservoir located upstream. The reservoir release increases the regulated flow at the instream flow target control point prior to being diverted downstream. For purposes of reducing instream flow shortages, this particular diversion right should not be curtailed. The model-user can handle this situation by bracketing the *WR* record in the input file with *IF* records, with the same priority as the diversion right, that turn the instream flow requirement off and then back on again just before and after consideration of the *WR* record right.

Interactions Between Hydropower and Instream Flow Rights

Hydroelectric power releases also contribute to downstream regulated flows. The algorithms in the computer code automatically prevent hydropower rights from being curtailed as a result of instream flow requirements. Hydropower rights ignore instream flow requirements. For hydropower reservoirs, storage and energy requirements may be entered as separate *WR* records, if necessary, so that the reservoir storage (type 1 right) is constrained by instream flow limits on downstream water availability, but the turbine releases (type 5 or 6 right) are not.

Hydropower releases increase regulated and unappropriated flows at downstream control points. However, a next-month return flow option allows hydropower rights to appropriate streamflow one month and return it to the stream the next. This could allow hydropower to reduce rather than increase downstream flows in a particular month.

APPENDIX A
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Each of the terms included in this glossary is defined and discussed in more detail in various parts of the manual. Terms are defined specifically from the perspective of their use in this manual.

WRAP Computer Programs

WRAP - The term *Water Rights Analysis Package (WRAP)* refers to the set of Fortran computer programs, *WRAP-SIM*, *WRAP-HYD*, and *TABLES*, which are documented by this manual. Other versions of *WRAP* related programs are cited in Chapter 1 and also noted below.

WRAP-SIM - This main program simulates a river/reservoir/use water allocation system.

WRAP-HYD - This utility program is used to develop hydrology input for *WRAP-SIM*.

TABLES - This postprocessor develops tables, data listings, and reliability indices from *WRAP-SIM* input and output files that organize/summarize the simulation results.

TAMUWRAP - The original 1988 version of the model was called the *Texas A&M University Water Rights Analysis Program (TAMUWRAP)*.

WinWRAP – The user interface facilitates executing the WRAP programs within Microsoft Windows in combination with other Microsoft programs.

WRAP2 - The *Water Rights Analysis Program-Version 2 (WRAP2)* in combination with *TABLES* replaced 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*. *WRAP3* is superseded by *WRAP-SIM*.

WRAPNET - *WRAPNET* provides the same modeling capabilities as *WRAP2*, but the internal computations are performed using network flow programming, a computationally efficient form of linear programming.

WRAPSALT - *WRAPSALT* expands *WRAP3* to incorporate features for considering salinity in assessing water supply reliability.

WRAPVIEW - The TNRCC and USGS developed *WRAPVIEW* by combining *WRAP* with the *ArcView* Geographical Information System (GIS) software package.

Spatial Configuration and Time Periods

control point - Control points are stations or nodes which provide a modeling mechanism for representing the spatial connectivity of system components. The locations of system features are defined by control points. The spatial configuration of the system is delineated by specifying the control point located immediately downstream of each control point.

computational time interval - A *WRAP* simulation uses a time step of one month.

hydrologic simulation period - In a *WRAP* simulation, specified annual water use requirements, distributed over the 12 months of the year, are met, subject to water availability, during a hypothetical repetition of historical hydrology represented by sequences of naturalized streamflows and net evaporation-precipitation rates for each month of a multiple-year hydrologic simulation period (which is also called the period-of-analysis).

Streamflow

available streamflow - The streamflow available to a water right is computed by *WRAP-SIM* as an initial step as each right is considered in the water rights priority loop which is embedded within the monthly loop.

channel losses - Channel losses represent the portion of the streamflow in the reach between two control points that is loss through infiltration, evapotranspiration, and diversions not reflected in the water rights. Channel loss L is treated as a linear function of the flow $Q_{upstream}$ at the control point defining the upstream end of the reach [$L = C_L\, Q_{upstream}$] where C_L is a channel loss coefficient provided as *WRAP-HYD* or *WRAP-SIM* input.

channel loss credits - Credits represent increases in streamflow to result from incorporating channel losses in *WRAP-SIM*. For example, diversions reduce streamflows at downstream control points less if channel losses are considered.

incremental streamflows - An incremental flow is the difference between total flows at adjacent control points. *WRAP* computational algorithms, as well as input and output data, are based on total flows rather than incremental flows. However, *WRAP-HYD and WRAP-SIM* include options for checking for negative incremental naturalized streamflows and adjusting the flows to remove the negative incrementals.

naturalized streamflows - Sequences of monthly streamflows representing natural hydrology are developed by adjusting historical gaged streamflow data to remove the impacts of reservoir construction, water use, and other human activities. Naturalized streamflows are provided as *WRAP-SIM* input data on inflow *IN* records.

regulated streamflows - *WRAP-SIM* computed regulated flows, associated with a particular control point, represent the physical streamflow after accounting for all the water rights. Regulated flows may be greater than unappropriated flows because a portion of the regulated flows may be committed to meet instream flow requirements or downstream diversion or storage rights.

streamflow depletions - *WRAP-SIM* computed streamflow depletions are the amounts appropriated to meet water rights diversions, account for reservoir net evaporation-precipitation, and/or refill reservoir storage. Each streamflow depletion is associated with a particular water right.

unappropriated streamflows - *WRAP-SIM* computed unappropriated flows, associated with a particular control point, are the portions of the naturalized streamflows still remaining after

the streamflow depletions are made and return flows are returned for all the water rights included in the simulation.

Distribution of Naturalized Streamflows from Gaged to Ungaged Locations

drainage area ratio method - Naturalized flows at an ungage site are estimated from flows at a gaged location based on proportioning the flows in proportion to the drainage areas of the gaged and ungaged watersheds. $Q_{ungaged} = R_{DA} Q_{gaged}$ where R_{DA} is the drainage area ratio

curve number method adaptation - This method of distributing flows described in Chapter 6 is based on a modified version of the Natural Resource Conservation Service (NRCS) rainfall-runoff modeling methodology which uses the curve number *CN* to represent the land cover and soil types of the watersheds.

flow distribution equation - The equation $Q_{ungaged} = a (Q_{gaged})^b + c$ is used with coefficients a, b, and c provided as input. With default values of one and zero for *b* and *c* and the drainage area ratio used for the coefficient *a*, the equation reduces to the drainage area ratio method.

watershed flow option - This *WRAP-SIM* option restricts the amount of water available to a water right to naturalized streamflow at its location computed by multiplying the naturalized flows input for the control point assigned to the water right by a factor which typically will be a drainage area ratio. Multiple water rights assigned to the same control point can have different limits on the amount of naturalized streamflow available to them.

Evaporation and Precipitation

adjusted net evaporation-precipitation - The model includes an option to account for the portion of the reservoir water surface evaporation and precipitation that is also reflected in the naturalized streamflow inflows. The ratio of reservoir surface area to watershed area is used to determine the proportion of the naturalized streamflow that is runoff from the land now covered by the reservoir. The net evaporation-precipitation rate is adjusted to prevent double-counting this inflow.

evaporation - Evaporation from the water surface of reservoirs is included in the volume accounting computations.

net evaporation-precipitation - evaporation minus precipitation. Evaporation represents a loss of water from the reservoir. Conversely, precipitation is a gain.

net evaporation-precipitation rate - Monthly rates expressed as depths of evaporation minus precipitation are provided as input to the model in inches, feet, or other units of depth per month.

net evaporation-precipitation volume - In the water volume accounting computations, the monthly net evaporation-precipitation volume is determined as the rate (depth/month) multiplied by the average surface area of the reservoir for the month.

precipitation - Precipitation falling directly on the water surface of reservoirs is included in the reservoir volume accounting computations through the net evaporation-precipitation depth.

Water Rights

backup right - A backup water right activated by *SO* record field 6 adds any diversion shortage incurred by the other right being backed-up to its own diversion requirement. Thus, multiple rights may be assigned to meet a particular diversion requirement. The secondary backup right supplies the diversion requirement only to the extent that the other right can not due to insufficient water availability.

constant inflow or outflow - An option allows a set of 12 flows for the 12 months of the year entered on *CI* records to be either added or subtracted from streamflow each year. This flows may represent intrabasin or interbasin water transport, return flows from groundwater sources, losses or other flows not otherwise reflected in the water rights input.

diversion - Computed by *WRAP-SIM* as permitted diversion target limited by water availability. The inputted water supply diversion requirement minus the computed actual diversion is the computed shortage.

drought index - A drought index (*DI/IP/IS* records) allows diversion, instream flow, and hydropower requirements to be specified as a function of the storage content of specified reservoirs. The drought index is expressed in the format of a table of storage content versus a percentage multiplier which is applied to the target diversion, instream flow, or hydropower amount associated with a water right. A particular drought index may be assigned to any number of water rights.

instream flow requirement - A water right requirement entered on a *IF* record consists of placing a minimum target limit on the regulated flows at a control point. The objective is to maintain regulated streamflows at or greater than the target is feasible.

natural priority option - Water right priorities are ordered internally within *WRAP-SIM* in upstream to downstream order if the natural priority option is specified in the *JD* record field 11. This ranked order is used in lieu of the water right priorities entered on *WR* records.

permitted, authorized, or target diversion - the diversion requirement or target amount of water to be appropriated from streamflow at a control point location and reservoir storage at the same or other locations.

permitted, authorized, or target energy requirement - hydroelectric energy generation target.

priority - an integer value associated with a water right indicating the seniority of the right relative to all the other rights. In each period of the simulation, water rights are considered in turn and available water appropriated in order of their relative priorities.

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

return flow - An amount of water computed as the diversion multiplied by an inputted return flow factor is returned to the stream system at a user-specified control point in either the same month as the diversion or the next month. Return flows may also be modeled as constant inflows entered on *CI* records.

target series - Diversion, instream flow, and hydropower requirements are often modeled as varying seasonally but being constant from year to year. However, the target series *TS* record allows specifying targets that vary between years as well as between months.

senior or junior rights - A water right is senior or junior relative to another water right depending on the priority number included in the input data for each right. A senior right has the highest priority, which is represented by the smallest priority number (earliest date or other priority indicator) and is considered first in the water allocation computations.

shortage - diversion target minus actual diversion or energy target minus actual energy produced. A shortage is the amount of a diversion or energy target not supplied due to insufficient streamflow and/or reservoir storage being available to meet the full target.

streamflow depletion limit - Limits may be placed on the amount of streamflow a right can appropriate in a calendar year or any month of the year to meet streamflow and storage targets.

target - diversion, instream flow, or hydroelectric power generation demand/need/requirement associated with a water right. Targets are met to the extent allowed by water availability.

type 1 water right - allows a permitted water supply diversion target and/or storage target in one reservoir to be met from streamflow depletions and releases from one or multiple reservoirs.

type 2 water right - is the same as a type 1 right except a reservoir storage target (refilling of storage capacity in the one reservoir) is not allowed.

type 3 water right - is the same as a type 2 right except the permitted diversion target can be met only from reservoir releases.

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

type 5 water right - is the same as a type 1 right except a hydroelectric energy generation target is specified rather than a diversion.

type 6 water right - is the same as a type 3 right except a hydroelectric energy generation target is specified rather than a diversion.

type 7 water right - discharges into the stream, designed for modeling priority return flow.

water right - A *WRAP* water right is a set of water management and use requirements associated with either a water right *WR* record or instream flow *IF* record and supplemental records associated with the *WR* or *IF* record. A water right may include specifications for water

supply diversion, return flow, hydroelectric energy generation, instream flow, and/or reservoir storage.

water use distribution coefficients - Each annual diversion, instream flow, and hydropower target is distributed over the 12 months of the year by a set of 12 multiplier factors entered on *UC* records.

Hydroelectric Power

energy requirement - An annual energy target in units of megawatt hours per year or similar units is entered in field 3 of a *WR* record. *WRAP-SIM* determines a monthly energy target by combining the annual target with monthly distribution factors (*UC* records) and an optional drought index (*DI/IP/IS* records). The energy target is determined in the same was as a diversion target.

head - the vertical water surface elevation difference between upstream and downstream of the turbines used in the power equation (Equation 4-4). *WRAP-SIM* computes head as a reservoir water surface elevation minus tailwater elevation.

lakeside versus downstream water supply release - *WS* record field 11 allows specification of whether or not water supply diversions are used to generate energy for more junior hydropower rights. By default, diversions for senior water rights are allowed to pass through the turbines to generate power for junior hydropower rights. However, the lakeside diversion option activated by *WS* record field 11 for a diversion right results in the diversion bypassing the turbines and not contributing to power generation.

secondary energy - additional hydroelectric energy, above the permitted energy target, which could be generated incidentally by pass-through flows and releases for more senior water right diversions.

tailwater - The water surface elevation downstream of a hydropower plant is used to compute head. The tailwater elevation may be entered as a constant (*WS* record field 9), or alternatively a table of tailwater elevation versus discharge (*TE/TQ* records) may be entered.

turbine capacity - An optional discharge capacity (*WS* record field 12) in volume/month may be input as an upper limit on the amount of water that can be released through the turbines to generate energy each month. If not otherwise specified the turbine discharge capacity is assumed to be unlimited.

turbine inlet elevation - The optional inlet elevation entered in *WS* record field 13 sets a minimum pool level below which power generation is curtailed. Power generation with all releases for all rights is constrained by the turbine inlet invert. Releases for a particular right are also constrained by the specified inactive pool. For a hydropower right with the inactive pool set higher than the turbine inlet, power generation with pass-through flows and water supply releases for other rights are constrained only by the turbine inlet elevation. Additional releases for the hydropower right are also constrained by the specified inactive pool.

Reservoirs

active pool - reservoir storage pool from which releases and withdrawals are made.

inactive pool - the bottom pool of a reservoir from which releases or withdrawals cannot be made except by evaporation.

multiple-reservoir system operations - A single water right diversion, instream flow, or hydroelectric power target may be met by releases from up to 20 reservoirs. Multiple-reservoir release rules are based upon balancing the storage content expressed as a percentage of capacity in specified vertical active pool zones of each system reservoir.

primary and secondary reservoirs - Up to 20 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, instream flow, or hydropower requirements but cannot be refilled by the water right. A secondary reservoir for one water right can be a primary reservoir for another water right and vice versa.

seasonal rule curve operations - A model option (*MS* record) allows the storage capacity of a reservoir to vary monthly over the 12 months of the year. The primary application of this option is modeling reservoirs with operating plans based on seasonal allocations of storage capacity between flood control and conservation pools.

storage-area relationship - A relationship between reservoir storage volume and water surface area is required in the computation of net evaporation-precipitation volumes. This relationship may be input alternatively as a storage versus area table (*SV/SA* records) or as coefficients for an equation (*WS* record fields 4, 5, 6).

storage-elevation relationship - A relationship between reservoir storage volume and water surface elevation is required in the computation of head in the hydropower routine. This relationship is input as a storage versus elevation table (*PV/PE* records).

zones 1 and 2 - For purposes of refining the specification of multiple-reservoir operating rules, reservoir active pools may be divided into an upper and lower zones illustrated in Figure 4-1 by use of *OR* records. Release decisions are based on balancing the storage contents of comparable zones in multiple reservoirs in terms of contents as a percentage of zone capacity.

Availability/Reliability Indices

exceedance frequency - the percentage of the total months in the overall simulation period-of-analysis that a particular amount is equaled or exceeded. *TABLES* develops exceedance frequency relationships for naturalized, regulated, and unappropriated streamflow, instream flow shortage, and reservoir storage.

period reliability - the percentage of the total months (periods) in the overall simulation period-of-analysis that a specified diversion target or hydroelectric energy target is met.

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

APPENDIX C
MODIFICATIONS

WRAP dates back to the 1980s. This appendix notes modifications since the 1996 version of the model. The first, second, and third editions of the *Reference/Users Manual* immediately preceding the current March 2003 *Reference and Users Manuals* are dated August 1999, October 2000, and July 2001. A number of revised versions of *WRAP* with interim documentation have been distributed in between the updates of the manuals.

Modifications Between 1996 and August 1999 Versions of WRAP

New features in the August 1999 *WRAP* that were not in the 1996 model include the following.

- a set of routines for adjusting gaged streamflows to determine naturalized flows
- methods for distributing naturalized streamflows from gaged (known-flow) to ungaged (unknown-flow) control points
- options to facilitate compilation of sequences of net evaporation-precipitation rates
- an adjusted net evaporation-precipitation option to account for the runoff from the land area now covered by a reservoir
- capabilities for modeling channel losses
- a set of optional capabilities for modeling instream flow requirements
- a drought index feature allowing instream flow, diversion, and hydropower targets to be expressed as a function of reservoir storage content
- expanded options for modeling return flows
- capabilities for developing streamflow-frequency relationships
- improved techniques for dealing with negative incremental naturalized streamflows
- options for adding sets of inflows and/or outflows to the naturalized streamflows
- an optional routine for assigning water right priorities by type of use
- water rights options associated primarily with off-channel reservoirs involving diversions from multiple locations and annual and monthly limits on streamflow depletions
- a water rights feature allowing diversion shortages associated with a right to be supplied by other rights
- an option for modeling seasonal rule curve reservoir operations
- features for finding errors in the input data
- improvements in input data format, file organization, and input/output data management
- refinements in the structure and organization of the Fortran code

Modifications Between August 1999 and July 2001 Versions of WRAP

Modifications made to *WRAP* between August 1999 and July 2001 are listed as follows. Input data records used to activate new features are shown in parenthesis. The changes between October 2000 and July 2001 were relatively minimal compared to the changes between the August 1999 and October 2000 versions. Most of the following additions were included in the October 2000 as well as July 2001 versions. The July 2001 version included addition of negative incremental flow option 5, expansion of *TO* record options, further increases in dimension limits, and several other relatively small refinements made after the October 2000 version.

- The system for detecting errors in the input data has been improved and expanded. Significantly more error checks have been added.

- A new naturalized streamflow distribution option allows channel loss computations to be combined with the NRCS curve number method. (*CP* record field 6, new option 8)

- The routine for adjusting evaporation-precipitation depths for runoff from land covered by reservoirs has been restructured for greater flexibility. (*JD* record field 10, *JC* record field 13, *CP* record field 9)

- A new negative incremental flow adjustment feature allows control points with synthesized flows to be optionally included or excluded in the negative incremental flow adjustments. (*JD* record field 8, *JC* record field 11)

- Various computational algorithms and the organization of the Fortran code have been refined. Inconsistencies and errors have been corrected. Improvements in certain routines reduce run times. Modifications facilitate compiling the code with different Fortran compilers. Restructuring in some cases makes the code easier to understand.

- Dimension limits have been increased to allow more control points, water rights, reservoirs, and drought indices.

- Input data optionally may be in a comma-delimited format as an alternative to fixed field widths for most input records for all three programs.

WRAP-SIM Modifications

- New features have been added to provide greater flexibility for specifying water right requirements. A new option allows diversion, instream flow, and hydropower targets to be entered as a time series covering the entire hydrologic period-of-analysis. The monthly targets may be varied from year to year or repeated for any number of years. (new *TS* record)

- Another new set of options allow diversion and instream flow targets to be defined as a function of: naturalized, regulated, and/or unappropriated streamflow at multiple locations; reservoir storage and/or drawdown; and/or streamflow depletions incurred by other water rights. A new drought index feature further facilities use of a drought index in combination with these options for defining water use targets. With the target building features, an option allows selection of the stage of the target for which the target and shortages are recorded in the output. (new target options *TO* record, *DI* record field 3, *SO* record field 9)

- Monthly and/or annual limits may be placed on the amount of water a right may withdraw from reservoir storage. (*SO* fields 7-8)

- Several water districts, cities, and other water supply entities may each control certain portions of the storage capacity of a reservoir. A reservoir evaporation-precipitation allocation routine has been developed to facilitate modeling of storage capacity shared by multiple water right holders. (new *EA/EF* records)

- The following new hydropower features provide more modeling flexibility. Power generation may be limited to releases from reservoir storage and by turbine elevation and discharge capacity. A tailwater rating curve may be entered as an option to a constant

tailwater elevation. Releases may increase downstream flows either the next month or same month. Computational algorithms have been refined. (*WS* fields 9, 12, 13; new *TQ/TE* records)

- A natural priority option has been added that overrides the water rights priorities with rights being considered in upstream to downstream order. (*JD* record field 11)

- Negative incremental flow option 5 previously developed by HDR, Inc. for *WRAP* applications in specific river basins was added to the generic model. (*JD* record field 8)

WRAP-HYD Modifications

- A new optional columnar table format facilitates transfer of streamflows and evaporation-precipitation depths to and from spreadsheet programs such as *Microsoft Excel*. (restructured *JC* record)

- Tables displaying intermediate computational results have been added for reservoir adjustments, incremental watershed parameters, and negative incremental flows. (*JC* and *RS* records)

- Regression equations have been added to facilitate adjusting streamflows by combining the results of a precipitation-runoff model with *WRAP-HYD*. (new *EQ* record)

- Tables displaying intermediate computational results were added for reservoir adjustments, incremental watershed parameters, and negative incremental flows.

TABLES Modifications

- A new option allows tables of naturalized flows, regulated flows, unappropriated flows, streamflow depletions, diversions, diversion shortages, instream flow shortages, channel losses, and/or reservoir storage to be developed in a columnar format. This facilitates data manipulation and plotting in spreadsheet or graphics software such as *Microsoft Excel*. (*2NAT, 2REG, 2UNA, 2DEP, 2DIV, 2SHT, 2IFS, 2CLO, 2CLC, 2STO* records)

- A new *2DIV* record has been added to develop tables for diversions in the same optional formats as the other variables noted above. (new *2DIV* record)

- A new option allows the computation of period reliabilities to either include or exclude months with zero demand. (*2REL* record)

- The format of the reliability table has been changed to replace the shortage summary with the corresponding percentage-of-time demand targets are met. The same basic information is provided in a more convenient format. Messages are also printed in the reliability table whenever demand targets are zero. (*2REL* record)

- Job Type 3 routines have been restructured for better clarity and flexibility. A new option allows regulated streamflows to be converted to input records to be read by *WRAP-SIM* as *TS* record instream flow target series. (*3NAT, 3REG, 3UNA, 3DEP, 3U+D* records)

- The input format has been restructured for the percentage storage and drawdown-duration tables and multiple-reservoir system release tables. (*2PER, 4SWR, 4SGP* records)

- A *TABLES* output filename may now have a different root than the input filename. Several more input error checks/messages have been added. The format of various output tables has been revised slightly.

- Several other modifications in *TABLES* were made to deal with new features and changes in *WRAP-SIM* including new input records, changes in format of water rights identifiers, and changes in dimension limits.

Modifications Between July 2001 and January 2003 Versions of WRAP

The new user interface program *WinWRAP* was added to WRAP.

WRAP-SIM Modifications

- The *FY* record routine for computing a yield-reliability and firm yield table was added.

- The *WR* record type 7 right and *SO* record *RETURN* options were added to allow prioritization of return flows.

- The *WR/SO* record backup right routine was modified to ignore intervening *IF* record rights.

- An annual limit on diversions was added to the *SO* record.

- The *SO* record monthly and annual diversions limits were extended to include type 3 rights.

- The *TO* record lower and upper limits on targets were restructured.

- The multiplier factor and parameter limit *XL* record and associated options were added. Flexibility is provided for conversion factors.

- An option was added for placing upper and lower bounds on the CN and MP used in applying the curve number method to distribute flows from gaged to ungaged sites.

- The system (*SO* record field 9) for selecting targets and shortages to output was expanded and clarified.

- Flexibility was added to sequencing of backup right.

- The flow input filename (root.INF) extension INF was changed to FLO because Windows uses the extension INF for a designated type of file.

- Read statements were modified to automatically remove trailing blanks so that alphanumeric identifiers do not have to be right justified.

- Several new error messages were added. Several dimension limits were increased.

- Programs were restructured to initialize variables without Fortran data statements, which were removed. This does not affect model application, but does account for the greatly reduced storage size.

TABLES Modifications

- The diversion and instream flow target tables (2TAR and 2IFT records) were added.

- A routine was added for performing a frequency analysis for the total monthly storage in any selected group of reservoirs, with the output provided at the bottom of a 2FRE record table for reservoir storage.

- The supplemental 2RET table was added to the 2REL table for use particularly when target building options complicate the interpretation of reliabilities.

- The UNIT record was added for specifying units in table headings.

- A water right group summary was added to the 1SUM record table.

- Modifications were made to the 1SUM and 1SRT tables to reflect revisions to *WRAP-SIM*.

- Read statements were modified to automatically remove trailing blanks so that alphanumeric identifiers do not have to be right justified.

- Several new error checks were added. A few headings were refined. Several dimension limits were increased. The program no longer reads past ENDF record.

WRAP-HYD Modifications

- The multiplier factor and parameter limit *XL* record and associated options were added.

- The monthly factor *MF* record was added.

APPENDIX D
WRAP-SIM FORTRAN CODE INFORMATION

Introduction to Appendices D, E, and F

Appendices D, E, and F are designed to facilitate examining the *WRAP-SIM*, *TABLES*, and *WRAP-HYD* Fortran code. The three executable programs are applied by model-users without concern for the actual internal code. However, continued modification and expansion of the model is expected. Reviewing the Fortran code may also be of interest to some users as an aid in understanding the computational algorithms or troubleshooting problems. Comment statements are used liberally throughout the code for explanation. However, Appendices D, E, and F are also essential to anyone interested in understanding the Fortran programs.

The *WRAP* programs conform to both Fortran 90 and 95 standards with relatively minor exceptions involving use of older capabilities that are still maintained by most compilers. The only non-standard feature in *WRAP-SIM* and *WRAP-HYD* is use of fixed form source code with 72-character records, which is standard in Fortran 90 but an obsolescent feature in Fortran 95. The only other non-standard features in *TABLES* are the use of *DATE* and *TIME* statements for the cover page and *ASSIGN* statements to set variable format numbers in several routines.

Recent versions of the executables were compiled with Compaq Visual Fortran Version 6.6 (copyright 2000) integrated with the Microsoft Visual Development Environment. The following setting is used to obtain carriage returns to facilitate writing and reading the 102-character length records in the *WRAP-SIM* direct access output file:

Project/Settings/Fortran/Compatibility/PowerStation 4.0 Compatibility Options/ Other Run-Time Behavior

The Fortran code is fully compatible with the Microsoft Fortran PowerStation compiler.

Overview of the Organization of WRAP-SIM

The Fortran program *WRAP-SIM* is organized as follows.

- Module *COMVAR* (COMmon VARiables) located at the beginning of the program specifies the type and dimension limits for variables used in common by the main program and subroutines.

- The main program is organized around the nested annual, period (monthly), water rights, and instream flow requirement loops shown in Figure 2-1 of Chapter 2. Certain computations are performed within the main program. Simulation results are written from the main program.

- The subroutines listed later perform specific computational and data management tasks. The majority of the subroutines are called one or more times from the main program. Subroutines are also called by other subroutines.

The simulation process is outlined in Figure 2-1 of Chapter 2. The *WRAP-SIM* data management and computational algorithms proceed through the following tasks.

1. The simulation is organized and controlled within the Main Program. Many computations are performed by the main program, and many are performed by the subroutines. At the beginning of the simulation, the Main Program calls Subroutines FILINI, WRAPIN, RANKWR or NATURAL, and IACNP as noted below.

2. Subroutine FILEINI (file initiation) conducts the interactive session in which the model-user provides filenames, reads the FO record from the root.DAT file, and opens the files.

3. Subroutine WRAPIN (WRAP input) reads all of the data from the root.DAT file (unit 3) and performs various manipulations to organize the data. WRAPIN is organized by input record type, reading the records sequentially from the DAT file.

4. Either Subroutine RANKWR (rank water rights) of Subroutine NATURAL (natural priority option activated by JD record field 11) develops the array RANK(WR) where WR=1,NWRTS in ranked order and RANK(WR) is the order in which the rights are read from the root.DAT file. RANK(wr)=1 for the first right read and RANK(wr)=NWRTS for the last right read. With the Subroutine RANKWR priority ranking system, WR=1 refers to the most senior right in the model, and WR=NWRTS refers to the most junior. NWRTS is the total number of water rights (WR and IF records) counted by Subroutine WRAPIN.

5. Subroutine IACNP (incremental watershed area, curve number, and precipitation) reads the DIS file (unit 8) which contains the FD, FC, and WP records. Incremental watershed areas, curve numbers, and mean precipitation are determined. The watershed parameters read and organized by Subroutine IACNP are used later by Subroutine FLDIST.

6. As shown in Figure 2-1, the simulation computations are performed within a water rights priority loop, nested within a monthly loop, nested within an annual loop. The loops are controlled by the Main Program with subroutines being called to perform specific tasks.

7. At the beginning of the annual loop, Subroutine INFEVA (inflows and evaporation) reads the IN and EV records for all control points for that year from either INF and EVA files (units 1 and 2), the DAT file (unit 3), or a HYD file (unit 12). Subroutine INFEVA performs various manipulations to organize the naturalized streamflows [INFLOWS(cp,mt)] and evaporation-precipitation rates [EVAPR(cp,mt)] including placing them in the same order as the *CP* records.

8. Subroutine FLDIST (flow distribution) distributes flows [INFLOWS(cp,mt)] from known-flow [INMETHOD(cp)=1] to unknown flow [INMETHOD(cp)>2] control points. Subroutine FLDIST also adjusts evaporation-precipitation depths [EVAPR(cp,mt)] for the runoff from land covered by reservoirs.

9. If pertinent negative incremental inflow adjustment options are specified, the Main Program calls Subroutine INCREM (incremental) to perform the adjustments [CPFLOW(cp,mt,1)] for the flows read by Subroutine INFEVA. The flows synthesized by Subroutine FLDIST optionally may be included or excluded in the negative incremental flow adjustments.

10. The water rights simulation computations are then performed within the water rights priority loop nested within the monthly loop. In each month, for each right in turn: (1) its target amount [AMT] is set, (2) water availability is determined based on streamflows [CPFLOW(cp,mt,2)] at that and all downstream control points, (3) water allocation

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computations are performed to meet the target, and (4) streamflows [CPFLOW(cp,mt,2)] are adjusted at that and all downstream control points for the effects of the right. The iterative loops are controlled within the Main Program. Subroutines are called by the Main Program as appropriate to perform specific computations.

11. Instream flow computations may cause a second pass through the task 10 water rights loop. The second pass occurs only if (a) the dual-pass instream flow option is used and (b) instream flow targets are not met in a particular month.

12. At the end of the water rights loop, data listed in Table 3-9 are written to the OUT file (unit 4), and the optional HRR file (unit 13) is written. Data listed in Tables 3-10 and 3-11 are written to the OUT file (unit 4) at the end of the monthly loop. The output is written from the main program.

WRAP-SIM Input and Output Files

Unit	Filename	Type	Contents
3	root.DAT	input	main input file
1	root.INF	input	IN records
2	root.EVA	input	EV records
8	root.DIS	input	FD, FC, WP records
12	root.HYD	input	IN and EV records
21	root.FAD	input	FA records
4	root.OUT	output	simulation results
14	root.MSS	output	error and trace messages
13	root.HRR/YRO	output	hydropower & reservoir releases yield-reliability output table
10	-	scratch	intermediate results
11	-	scratch	intermediate results

Subroutines

FILEINI – file initiation routine called by main program to open input and output files.

CHECK – called by subroutine FILINI to check whether files exist.

WRAPIN – called by main program to read and organize the input data, except for the data related to hydrology (all records except *IN*, *EV*, *FD*, *FC*, *WP, FA* Records).

DROUGHT - called by main program to compute the drought index as a function of reservoir storage.

CONFLU – called by subroutine WRAPIN to determine the first downstream control point common to a water right and secondary reservoir and to specify whether the reservoir releases are limited to diversions at downstream locations.

RANKWR – called by main program to develop the array RANK(WR) which identifies the water rights in priority order.

NATURAL - called by main program to develop the array RANK(WR) which identifies the water rights in ranked order from upstream to downstream, if natural priority option is activated.

INFEVA – called by main program to read the streamflow *IN* and evaporation *EV* records and arrange them in the same order as the control points.

INCREM – called by main program to determine negative incremental flows and to adjust the streamflows in accordance with the option specified on the *JD* record.

AVALB – called by main program to determine the amount of streamflow available for a water right.

MINFLO – called by main program to determine the diversion requirement for a type 4 right.

RELEASE – called by main program to determine releases from secondary reservoirs.

INFADJ – called by main program to reduce and increase the available streamflow at pertinent control points by the streamflow depletion and return flow, respectively.

CUMREL –called by subroutine RELEASE to accumulate releases form secondary reservoirs to downstream water rights.

RESCAL – called by main program and subroutines RELEASE and POWER to perform calculations to determine reservoir net evaporation-precipitation and end-of-period storage volumes and also includes EA record allocation.

LINEAR – called by main program and MINFLO, RECAL, and POWER to perform linear interpolation.

POWER – called by main program to perform hydroelectric power calculations.

SPRING - called by main program to adjustment naturalized streamflows by adding flows read from the flow adjustment FAD file.

IACNP – called by main program to read the flow distribution file and determine the parameters for the total and/or incremental watersheds.

FLDIST – called by main program to distribute flows from gaged to ungaged control points. FLDIST also has a reservoir evaporation-precipitation rate adjustment routine.

CURNUM – called by subroutine FLDIST to transfer flows using the modified NRCS CN method.

BISECT – called by CURNUM to solve the NRCS curve number equation for P given Q using the iterative bisection method.

Parameters for Defining Array Dimensions

The arrays in the Fortran code are dimensioned to reserve memory space. Parameter statements are used to facilitate changing dimension limits. Many but not all of the array dimensions are set by the parameters listed below with their current values. These parameters setting the array dimensions are located at the beginning of Module COMVAR which is at the beginning of the program.

MAXWR   = 5,000 maximum number of water rights (*WR* and *IF* records)
MAXCP   = 5,000 maximum number of control points (*CP* records)
MAXRES   = 1,500 maximum number of reservoirs
MAXMON   = 12 maximum number of periods per year
MAXUSE   = 100 maximum number of use types (*UC* records)

MAXRF   = 50 maximum number of set of monthly varying return flow factors (*RF* records)

MAXTAB   = 100 maximum number of storage-area tables (*SV/SA* records)

MAXGP   = 30 maximum number of water rights on *WO* records or groups on *GO* records

MAXRSO   = 30 maximum number of reservoirs/hydropower plants on *RO* records for output

MAXPOW   = 100 maximum number of hydropower reservoirs

MAXSYS   = 20 maximum number of reservoirs associated with a water right

MAXSTO   = 100 maximum number of type 4 storage-flow rights

MAXGAG   = 15 maximum number of upstream gages on *FD* records

MAXDI   = 100 maximum number of drought indices

MAXEA   = 50 maximum number of *EA* records

MAXTO   = 650 maximum number of *TO* records plus backup rights on *SO* records

Definition of Variables

The variables incorporated in *WRAP-SIM* are listed and defined as follows. Two items of information are provided in brackets following the description of each variable:

1. variable type (real, integer, character, logical)

2. location specified as either the main program or a specific subroutine. Locations are not specified for the variables included in module COMVAR which are used in common by the main program and/or multiple subroutines. The majority of the variables are included in module COMVAR.

ACPID - identifier of alternative control point input on SO record [character]

ADJAMT - temporary value for monthly target AMT [real, main program]

ADJINC – JD record entry defining negative incremental inflow option to be used [integer]

AMT – annual or monthly diversion, instream flow, or hydropower target [real]

AMTIF - computed monthly instream flow target [real, main program]

AMT1 – diversion requirement interpolated from storage-flow table [real, MINFLO]

AMT1, AMT2, AMT3, AMT4 – Intermediate monthly target amounts written to output file as specified by ISHT(wr) from the SO record [real, main program]

ANNDEP(maxwr) - annual streamflow depletion limit specified on SO record [real]

ANNDIV(maxwr) - cumulative annual streamflow depletion since January [real, main program]

ANNRES(maxwr) – annual accumulative amount withdrawn from reservoir; annual accumulation of RESW(maxwr) [real, main program]

AREAVE – average reservoir surface area [real, RESCAL]

ARW(maxwr) - annual limit on withdrawals from reservoir storage from SO record [real]

ASF – amount available from streamflow after reservoir evaporation-precipitation [real, main program]

AVAIL – available water to a point [real, AVALB]

AVAMT – available streamflow at a control point [real]

AVFLAG - flag used in Subroutine AVALB to specify skipping certain computations. AVFLAG=9 if Subroutine AVALB is called by Subroutine INCREM. AVFLAG=99 if final unappropriated flows are being determined at completion of water rights loop. [integer]

BEGSTO - beginning-of-period reservoir storage [real, RESCAL]

BPAREA – beginning-of-period area [real, main]

BPAREA, EPAREA – beginning and end-of-period reservoir surface areas [real, RESCAL, POWER]

BPELEV – beginning period elevation [real]

BPSTOR – beginning-of-period storage [real, main]

BPSTOR,EPSTOR – beginning and end-of-period storages [real, POWER, RESCAL]

CD – record identifier [character]

CHANGE – checks current pass through control point system to check if an accumulated negative incremental has changed from previous pass [logical, INCREM]

CHCKST – flag enabling release decisions to be made with either end-of-period or beginning-of-period storage [integer, RELEASE]

CHR – interactive user input to control program execution [character, CHECK]

CI(12) - constant monthly inflows/outflows from *CI* record [real]

CIID - constant inflow control point identifier read from *CI* record [character]

CIN - constant monthly inflow/outflow applied at the control point specified on the *CI* record and at all downstream control points [real]

CINF(maxcp,12) - flows read from *CI* records to be added to the naturalized streamflows [real]

CL(maxcp) - channel loss factors read from *CP* records [real]

CLAD - divisor used in subroutine *AVALB* to adjust the amount of water available at a control point to reflect channel losses in successive reaches between that control point and a water right located upstream. [real]   CLAD=CLAD*(1-CL(cp))

CLFLAG - number of control points with channel losses (nonzero CL(cp)) [integer]

CLOSS(maxcp,1) - total channel loss credits associated with adjusting downstream flows, in response to streamflow depletions for diversions and refilling storage. [real]

CLOSS(maxcp,2) - total channel losses computed for the reach below the control point. [real]

CLX - multiplier to adjust streamflows for channel losses for each successive downstream reach. [real]
CLX = CLX*(1-CL(I))

CN(maxcp) - curve number. [real, IACNP]

CN1 - curve number from WP record. [real, IACNP]

CNGAGE(maxcp) - CN of incremental gaged watershed. [real, IACNP, FLDIST]

COEF(maxcp,1) - COEF1 for flow distribution equation. [real**,** IACNP, FLDIST]

COEF(maxcp,2) - COEF2 for flow distribution equation. [real**,** IACNP, FLDIST]

COEF(maxcp,3) - COEF3 for flow distribution equation. [real**,** IACNP, FLDIST]

COEF1 - coefficient in flow distribution equation read from FD record. [real**,** IACNP]

COEF2 - coefficient in flow distribution equation read from FD record. [real**,** IACNP]

COEF3 - coefficient in flow distribution equation read from FD record. [real**,** IACNP]

CONFL – index of first downstream control point common to both water right and secondary reservoir. [integer, RELEASE]

CPDT(maxcp,2) – inflow and evaporation multiplication factors for each control point [real]

CPFLOW (maxcp,maxmon,5) – miscellaneous flow values at a control point each month [real]

    CPFLOW(,,1) – negative incremental
    CPFLOW(,,2) – unappropriated flow
    CPFLOW(,,3) – summation of streamflow depletion
    CPFLOW(,,4) – summation of flows returned
    CPFLOW(,,5) – summation of depletion minus summation of releases used in making release
            decisions from secondary reservoirs

CPID(maxcp) – control point and next downstream control point identifiers [character]

CPIN(maxcp) – control point identifiers [character, INFEVA]

CPNXT(maxcp) – indices of the next downstream control point for each control point [integer]

CPNXTAUX(maxcp) - a copy of CPNXT. The next control point is changed to –99 when a control point is ranked. [integer, NATURAL]

CPOUT - input flag on JD record related to specifying which control points to output [integer]

CPRANK (maxcp) - control points ranking for upstream to downstream [integer, NATURAL]

CPRET(maxcp) – summation of return flows returned to each control point [real, main]

CPSUM(maxcp,4) – monthly control point summary data [real, main]

    CPSUM(cp,1) – diversion shortages
    CPSUM(cp,2) – permitted diversions
    CPSUM(cp,3) – reservoir evaporation volumes
    CPSUM(cp,4) – end-of-period storages

CRANK - current rank of the control points in the sorting from upstream to downstream [integer, NATURAL]

CUMEV(maxea) - cumulative net evaporation-precipitation associated with senior rights used in the EA record allocation method 1 [real RESCAL]

DA(maxcp) - drainage area [real]

DA1 - drainage area from WP record [real, IACNP]

DAG(maxcp,maxgag) - drainage area of upstream gage [real, IACNP]

DAGAGE(maxcp) - incremental drainage area of source gage [real, IACNP, FLDIST]

DAUGC(maxcp,maxgag) - drainage area of gages above ungaged control point [real, IACNP]

DAUG(I) - incremental drainage are of ungaged site [real, IACNP, FLDIST]

DEPLIM - maximum limit on the streamflow depletion allowed for a water right [real]

DELF - delivery factor = 1-CL(cp) [real, FLDIST]

DIFLAG - counter of the number of drought indices [integer]

DIFACT(maxdi) - drought index multiplier factor computer by Subroutine Drought [real]

DINUM(maxdi) - number of reservoirs used to define drought index [integer]

DIRES(maxdi,12) - reservoirs used for drought index [character]

DIPER(maxdi,10) - drought index in percent corresponding to DISTO(maxdi,10) [real]

DISTO(maxdi,10) - drought index in percent corresponding to DIPER(maxdi,10) [real]

DIV – streamflow depletion made by a right [real]

DIVSTO – streamflow depletion to replenish storage [real, POWER]

DRAWDOWN – reservoir storage capacity minus either beginning-of-period or end-of-period storage used to ser targets as specified by TO record [real, main program]

DSG - downstream gage identifier on *FD* record [character]

DUMMY(maxcp,maxmon) – temporary array of values [real, INFEVA]

DUMMY(maxtab,25) – interpolation table [real, LINEAR]

EAF(maxea,10) - multiplier factors from EF record [real]

EAFLAG - counter of the number of *EA* records [integer]

EANUM(maxea) - number of component reservoirs among [integer]

EAR(maxwr) – index from WR record connecting reservoir to EA record [integer]

EAREA(maxea,10) - component reservoirs on a EA record [character]

ELAVE – average elevation [real]

EMPTY - switch from DI record causing DI reservoir(s) to empty at beginning of month after the drought index is set [integer]

ENDSTO - end-of-period reservoir storage [real, RESCAL]

EPADJ - JD record entry specifying application of evaporation-precipitation adjustments [integer]

EPAREA – end-of-period area [real, main]

EPELEV – end-of-period elevation [real]

EPST1,EPST2 – subsequent estimates of end-of-period storage [real, RESCAL]

EPST1,EPST2 – subsequent estimates of end-of-period storage [real, POWER]

EPSTOR – end-of-period storage [real, main program and RELEASE]

ERR – difference between subsequent approximations [real, POWER, RESCAL]

ERRMAX – maximum allowable difference between subsequent end-of-period storage convergence criteria [real, RESCAL]

ERRMAX – maximum allowable error; convergence criteria [real, POWER]

ERROR – iteration convergence in hydropower computations [real]

EVACST – evaporation depth [real, RESCAL]

EVAPR(maxcp,maxmon) – net evaporation rates at each control point each month of a year [real]

EVCFA – first storage-area coefficient for a reservoir from WS record [real]

EVCFB – second storage-area coefficient for a reservoir from WS record [real]
EVCFC – third storage-area coefficient for a reservoir from WS record [real]

EVCURV(maxtab,25) – storage-area tables for evaporation computations [real]

EVOL – evaporation volume [real, main, POWER,RESCAL, RELEASE]

EWA(maxcp) - watershed area from *CP* record used to adjust net evaporation-precipitation for runoff from land covered by reservoir [real]

FACT(maxwr) - streamflow multiplier factor read from SO record to set targets [real]

FACTOR – factor multiplied by total net evaporation-precipitation to determine that portion allocated to EA record reservoir [real, RESCAL]

FIND – interpolated value [real, LINEAR]

FIRST – first secondary reservoir in system list [integer, RELEASE]

FLOWCL - available flow at a control point adjusted to reflect channel losses between that control point and an upstream water right [real]

FRMPOW – firm energy [real]

FUNCTION STILL_UNRANKED - Serves as a stop criteria for the NATURAL subroutine. The function returns a *true* value if there is at least one control point left to assign a rank number using the natural priority option. A control point is considered *unranked* if CPNXTAUX(cp) is different from -99. [logical, NATURAL]

GIVEN – value entering the table [real, LINEAR]

GPNUM – index of group identifier for each water right [integer]

GPOUT - input flag on JD record related to specifying which water rights to output [integer]

GROUP(maxgp) - identifiers of water rights to output specified on GO record [character]

HILO – flag to determine which storage zone to check [integer, RELEASE]

HISTOR – top of active pool [real, POWER]

ID - control point identifier on *FD* record [character]

IDNUM – primary reservoir identifier index [integer, LINEAR, POWER]

IDSET - input variable on JD record that selects between the two alternative sets of water rights identifiers [integer, WRAPIN]

IDSG(maxcp) - identifier for source gage from which flows are distributed [integer]

IFCT - Counter of the number of instream flow targets, which are not met. For IFFLAG=2, a nonzero value of ICFT during the first pass triggers a second pass through the water rights loop. [integer]

IFFLAG - Type of instream flow computations specified on an *IF* record. [integer]
(IFFLAG=RFMETH(wr) for *IF* record rights.)

IFLIMIT - limit on water availability resulting from instream flow requirement. The amount of water available to a right is the lesser of AVAMT or IFLIMIT. [real]

IFPASS - pass through the water rights loop used in conjunction with instream flow routine. IFPASS is 1 or 2 for the first and second pass. IFPASS is negative until the first nonzero IF right is reached in the priority loop. [integer]

IFREG - monthly instream flow requirement [real]
IFREG = IFTARGET(I) = INSTREAM * PDUSCF(USENUM,MT)

IFSHORT(maxwr) - monthly instream flow shortage [real]

IFTARGET(maxcp) - monthly instream flow target [real]
IFTARGET(I) = INSTREAM * PDUSCF(USENUM,MT)

IGAGE(maxcp,maxgag) - identifier for upstream gages [integer, IACNP]

IN – water into reservoir; same as INPOW [real, POWER]

IN, OUT – water made available to and required form by the current right [real, RESCAL]

INEST – estimate of water made available to reservoir [real, RESCAL]

INFLOW(MAXCP,MAXMON) – inflow at each control point each month of a year [real, common]

INISTO – flag determining initial storage at reservoir [logical, WRAPIN]

INMETHOD(cp) - method for providing naturalized flows for control point [integer]

INPOW – water into reservoir; same as IN [real, POWER]

INRES – inflow from a right into a reservoir [real, common]

INWS - flag from *CP* record indicating whether parameters are for total or incremental watershed [integer]

IR - counter and array index for reservoirs [integer]

IRF(maxwr) - integer identifier of the set of 12 monthly return flow factors for a water right [integer]

ISHT(wr) - switch on SO record controlling which shortage and target to write to output file [integer]

ISO – ISO = WRTO(wr) = counter and array index for variables on TO record [integer]

ITS - ITS = TSCOUNT = SERIES(wr) is an array index for QTS(YR,ITS,MT) of the set of TS records associated with the water right [integer, main]

J1 – integer identifier of SV/SA table foe EA record reservoirs; J1=RESNUM(I,2) [integer, WRAPIN]

LIMIT - component of IFLIMIT associated with a downstream control point [real]

LOC – control point location index [integer, AVALB]

LOCPT – control point indices [integer, CUMREL]

LOGNUM – index of control point [integer]

LOSS - channel loss [real]

LOSTOR, HISTOR – bottom and top of active pool [real, RESCAL]

LOWLIM - lower limit on target from TO record [real, main program]

MAKEUP – amount desired to release from secondary reservoirs after depletion is made [real]

MATCH – counter used in several error checks to flag whether certain conditions have been met [integer]

MAXIT – maximum number of iteration [integer, LINEAR]

MAXIT – maximum number of iterations. [integer, POWER]

MAXIT – maximum number of passes through the control point system accumulating negative incrementals. MAXIT=NCPTS+1 [integer, INCREM]

MAXRF - maximum number of *RF* records [integer]

MIN – table value index [integer, LINEAR]

MONDEP(maxwr) - constant monthly streamflow depletion limit specified on WS record [real]

MONLIM - monthly limit on streamflow depletion [real]

MONTH – month in which to place return flows [integer, INFADJ]

MP(I) - mean precipitation for control point I [real]

MP1 - mean precipitation from WP record [real]

MPGAGE(I) - mean precipitation of incremental gaged watershed [real]

MRW(maxwr) - monthly limit on withdrawals from reservoir storage from SO record [real]

MSD(20,12) - monthly-varying streamflow depletion limit specified on ML record [real]

MSFLAG - number of reservoirs with monthly varying (*MS* record) limits on storage. [integer]

MSRES - reservoir identifier for reservoirs with monthly varying (*MS* record) storage limits. [integer]

MT – current month of simulation [integer]

NAME*80 – file name [character, FILEINI, CHECK]

NAME*80 – file name [character, main]

NCP - integer identifier of control point [integer]

NCPOUT - number of control points to output specified on CO record [integer]

NCPTS – number of control points in a basin [integer]

NEA – EA record counter or index; NEA from EA record must equal EAFLAG [integer, WRAPIN]

NEAF(maxea) – net evaporation-precipitation allocation method specified on EA record [integer]

NEGINC - entry on JD record specifying writing negative incremental flows to MSS file [integer]

NEV - number of EV records read [integer]

NEXWR - SO record entry specifying backup or continuation water right [character]

NGAGE(maxcp) - number of gages located above the ungaged site[integer]

NGOUT - number of water rights groups to output specified on WO record [integer]

NIFLAG - negative incremental flow flag set by ADJINC on JD record [integer]

NIN - number of IN records read [integer]

NP - number of control points for which watershed parameters are determined [integer]

NPOPT – natural priority option entered on JD record [integer]

NPRDS – number of months in a year is 12 [integer]

NPT – index of next downstream control point [integer]

NPTABL – number of storage-elevation tables [integer]

NREOUT – number of reservoirs for output [integer]

NREOUT - number of reservoirs to output specified on RO record [integer]

NRES – total number of reservoirs [integer]

NRFS - counter of number of *RF* records [integer, WRAPIN]

NTORES – TORI(N) index of last reservoir or total number of reservoirs read on TO records [integer]

NTWTABL – number of tailwater tables [integer]

NUM – table identifier index [integer, LINEAR]

NUMPOW – number of hydropower rights in basin [integer]

NUSCP - identifier of the control point of the upstream end of a channel reach for which channel losses are being computed [integer]

NUSES – number of use types [integer]

NWOUT - number of water rights to output specified on WO record [integer]

NWP - total number of WP records [integer]

NWRREC - counter of the number of water rights written to output file [integer]

NWRTS – number of water rights in a basin [integer]

NYRS – number of years in a simulation [integer]

OLD – used as flag to determine if a reservoir has been entered with a previous right [logical, WRAPIN]

OUTEST – estimate of reservoir outflow to meet diversion and release requirements [real, RESCAL]

OUTPOW – water released from reservoir [real, POWER]

OUTPT – flag to output right, same as WRNUM(,6) [integer]

OUTRES – outflow from a reservoir [real]

OUTWR - number of water rights to output entered on JD record [integer]

P – index used in character data manipulation [integer, main, CHECK, FILINI]

PASSNG – amount of streamflow that a right passed above the first common downstream control point [real, RELEASE]

PDUSCF(maxuse,maxmon) - -use factors for each use each month [real]

POWFCT – conversion factor for hydroelectric energy computations. Converts flow per month and elevation into appropriate energy units in the equation [real]
$$energy = POWFCT * Q * H*eff$$

POWPRO – energy produced [real]

PREOUT,PREIN – water previously released and made available by senior rights [real, RESCAL]

PFLOW(maxto) – flow in previous month used to set target as specified by TO record [real, main]

PRIREL(maxsys) – indices of secondary reservoirs in priority order [integer, RELEASE]

PRTY(maxsys) – priority numbers of reservoirs [real, RELEASE]

PT – control point index [integer, RELEASE]

PTBCNT – counter of storage-elevation tables read [integer, WRAPIN]

PVCURV(maxpow,25) – storage-elevation tables for hydropower computations [real]

PYR – year being read [integer, INFEVA]

Q(maxcp,mt) - flows read from IN records [real]

QGAGE(maxcp) - incremental flows at gage [real]

QIN(mt) - flows read from IN records [real]

QTOTAL - total cumulative flows at ungaged site [real]

QTS(80,12,12) - diversion, instream flow, or hydropower targets read from TS record [real]

QUG(maxcp,mt) - incremental flows at ungaged site [real]

RANK(maxwr) – contains the indices of water rights in order of priority [integer]

RANKTEMP(nwrts) - Temporary array for the natural ranking of water rights using the ranking of control points CPRANK [integer, NATURAL]

RCP – return control point identifier [character]

RECORD – index of current record of direct access output file [integer, main]

REGFLOW(maxcp) - regulated flows computed at the completion of the first pass through the water rights loop reflecting the effects of all rights [real]

REL – reservoir release [real, CUMREL]

RELS – summation of releases from secondary reservoirs for a right [real]

RELSTO – secondary reservoir releases to replenish storage [real, POWER]

REOUID(j) - identifiers of reservoirs to output specified on RO records [character]

REOUID(MAXRSO) – reservoir identifiers listed on JR records [character]

REPEAT – identifier of control point from which to repeat data [character, INFEVA]

RES – temporary variables holding reservoir, control point, use, and group identifiers [character, WRAPIN]

RESDAT(maxres,13) – reservoir data occurring in a month [real]

> RESDAT(,1) – maximum storage capacity of all type 1 and hydropower rights
> RESDAT(,2) – EVCFA
> RESDAT(,3) – EVCFB
> RESDAT(,4) – EVCFC
> RESDAT(,5) – beginning-of-period storage
> RESDAT(,6) – end-of-period storage
> RESDAT(,7) – evaporation
> RESDAT(,8) – summation of depletions into a reservoir
> RESDAT(,9) – releases through outlet works (turbines) from reservoir
> RESDAT(,10) – "lakeside" releases from reservoir
> RESDAT(,11) – releases from system reservoirs
> RESDAT(,12) – hydroelectric energy produced
> RESDAT(,13) – highest firm power at reservoir

RESID(maxres) – reservoir identifiers [character]

RESNUM(maxres,4) – various indices pertaining to a reservoir [integer]

> RESNUM(,1) – control point location index
> RESNUM(,2) – index of storage-area table
> RESNUM(,3) – flag to output reservoir
> RESNUM(,4) – index of storage-elevation table
> RESNUM(,5) – index of tailwater elevation-discharge table

RESPT – reservoir location index [integer, CONFLU]

RESREL(maxcp) - the portion of the regulated flow at a control point that came from releases from upstream reservoirs for diversions located further downstream [real]

RESW(maxwr) – monthly amount withdrawn from reservoir to meet target [real, main program]

RETLST – return flow lost from system. Computed but not used. [real]

RETNUM – index of control point for return flows [integer]

RETURN – return flow [real]

RF(maxrf,12) - monthly return flow factors read from *RF* records [real]

RFAC – return flow factor [real]

RFID(maxrf) - return flow identifiers read from *RF* record [character]

RFIDWR - return flow identifier read from *WR* record. RFIDWR is matched with RF(maxrf) to assign a set of monthly return flow factors to a water right. [character]

RFLOW - intermediate value of regulated flow [real]
$$RFLOW = REGFLOW(cp) = CPFLOW(cp,mt,2) + RESREL(cp)$$

RFMETH(maxwr) - return flow method read from *WR* record. [integer]

        0,1 – constant factor, same month
        2 – constant factor, next month
        3 – monthly factor, same month
        4 – monthly factor, next month

ROOT – root of file name [character, FILINI]

ROOT – root of file name [character, main]

RUNOFF - precipitation runoff from land covered by reservoir used to adjust evaporation-precipitation depths [real, FLDIST]

SCPATH – path for scratch files [character, FILINI]

SERIES(maxwr) - controls use of targets from TS records serving as integer identifier (Abs(SERIES(wr))) of the set of TS records associated with a water right and whether to select maximum (+) or minimum (-) or add (SERIES*10000 flag) [integer]

SHT – diversion shortage for a right [real, common]

SPILL - a decrease in reservoir storage and corresponding increase in streamflow when end-of-period storage in the previous month exceeds the monthly varying storage limit from a *MS* record [real, main program]

STATUS - IOSTAT=STATUS in read statements, STATUS=0 if no Fortran format error, non-zero STATUS indicates an error in the data read [integer]

STBCNT – counter of storage-flow tables read [integer, WRAPIN]

STFL – index of storage-flow table for a type 4 right [integer, common]

STMON(12,maxmon) - monthly limits on reservoir storage capacity from *MS* records. [real]

STOFLG – flag to use either beginning-of-period or end-of-period storage when making reservoir release decisions [integer]
STOFLO(maxsto,25) – storage-flow tables for type 4 rights [real]

STORAGE - reservoir storage used to determine surface area [real, RESCAL]

STSYS – counter to determine the number of lines written to scratch files saving reservoir system and hydropower data [integer, WRAPIN]

SUMQ – sum of flows at upstream gages [real]

SYSNUM(maxsys+1,2) – indices if reservoirs associated with a water right. [integer]

       SYSNUM(,1) – reservoir indices
       SYSNUM(,2) – index of first control point located downstream of water right location and reservoir location
       SYSNUM(,3) – negative if a lakeside release

SYSOUT – JD record entry specifying output to system file [integer]

SYSRES,RESINT – reservoir indices [integer, RELEASE]

TAILWT - if TAILWT=0, a tailwater curve rate is expected [integer, WRAPIN]

TARA(24),TARB(24) –reservoir storage-flow, storage-area, and storage-elevation data [real, WRAPIN]

TARGET – target streamflow depletion [real, POWER]

TCAP(maxres) – turbine cpacity [real]

TELEV(maxres) – turbine elevation [real]

TEMP – temporary integer variable [integer, WRAPIN]

TEMP(MAXCP,2) –intermediate values of the incremental inflows [real, INCREM]

TEMPI – temporary integer variable [integer, RELEASE]

TEMPR – temporary real number [real, RELEASE]

TEMREL – release amount from a secondary reservoir [real, RELEASE]

TITLE1 – first title (on T1 record) [character]

TITLE2 – second title (on T2 record) [character]

TITLE3 – third title (on T3 record) [character]

TITLEO – first line of each output file [character, main program]

TOCP(maxto) - integer identifier of control point TOFLOW(n) from TO record matching CPID(cp,1) from CP record [integer]

TOCOMB(maxto) - TO record specification of method for combining targets [character]

TOFLAG(maxto) - flag of backup and continuation rights set by *BACUP* on SO record and *TOCONT* on TO record as follows: backup right, TOFLAG(n)=9; continuation right, TOFLAG(n)=90; both backup and continuation right TOFLAG(n)=99 [real]

TOFLOW(maxto) – TO record specification of streamflow or drawdown used to build target [integer]

TOLIM(maxto,2) - TO record lower and upper limits on target [real]

TORES(maxto) – reservoir identifier from TO record [character]

TORI(maxto) – integer identifier of reservoir TORES(n) from TO record matching RESID(res) from WS record [integer]

TOTAL – used to sum monthly use distribution factors to convert to decimal fractions [real, WRAPIN]

TOTCAP - total storage capacity of the EA record reservoirs [real, RESCAL]

TRY – flag to determine if flag exists [logical, CHECK]

TSCOM(20) - TSL from TS record specifying manner in which target from TS record is combined with preceding target; TSCOM(ITS)=TSL=MAX,MIN,ADD,SUB,MUL from TS record. [character]

TSCOUNT – ITS = TSCOUNT = integer identifier of the set of TS records read for a water right, counter of number of water rights with TS records [integer, WRAPIN]

TSL - TS record entry specifying combining of targets which is transferred to main program through TSCOM(ITS) [character]

TSYR1 - beginning year on TS record [integer]

TSYR2 - ending year on TS record [integer]

TSTOR – total storage in reservoirs associated with the right [real, MINFLO]

TWATER – tailwater elevation [real]

TWCURV (maxtab, 25) – tailwater curves [real]

TYPE – water right type [integer]

UGID(maxgag)*6 - upstream gage control point identifier from *FD* record [character]

USEID(maxuse)*6 – use type identifiers [character]

USEP(maxuse) – priority from UC record [integer]

USEM(maxuse) – factor from UC record by which priority numbers are multiplied [real]

USEFAC(maxuse) – factor from UC record by which target amounts are multiplied [real]

UPPLIM - upper limit on target from TO record [real, main]

USENUM – index of use type [integer]

WR – integer identifier of water right [integer]

WRDAT(maxwr,4) – water right data [real]

       WRDAT(,1) – annual permitted diversion or annual firm energy
       WRDAT(,2) – return flow factor
       WRDAT(,3) – bottom of inactive pool if only reservoir associated with right
       WRDAT(,4) – top of inactive pool if only reservoir associated with right

WRID(MAXWR)*6 – water right identifiers input on WR and IF records [character]

WRIDS(wr,1) - IF records do not have group identifiers like WR records. As IF records are read, Subroutine WRAPIN sets WRIDS(wr,1) equal to IF#IF*IF as a flag used by the main program to identify rights as being instream flow rights [character]

WRIDS(wr,1) - second water rights identifier (first group identifier) input on WR record [character]

WRIDS(wr,2) - third water right identifier (second group identifier) input on WR record [character]

WRNUM(MAXWR,11) – various water right flags and indices [integer]

        WRNUM(,1) – control point index
        WRNUM(,2) – use type index
        WRNUM(,3) – return control point index
        WRNUM(,4) – index or identifier of ML records
        WRNUM(,5) – type
        WRNUM(,6) – flag to output right
        WRNUM(,7) – priority number
        WRNUM(,8) – STFL
        WRNUM(,9) – index of primary reservoir or index of system data record in scratch file
        WRNUM(,10) – same as SYSNUM(,2) if only one reservoir listed
        WRNUM(,11) – same as SYSNUM(,3) if only one reservoir listed
        WRNUM(,12) - control point index for alternate control point ACPID entered on SO record

WROUT(30) - identifiers of water rights to output specified on WO record [character]

WRPT – water right location index [integer, CONFLU(K)]

WRSYS(maxsys,6) – data describing reservoir system for a water right with multiple reservoirs. This data is saved on UNIT10 and UNIT11 scratch files to conserve core memory. [real]

        WRSYS(,1) – storage at top of inactive zone or constant tailwater elevation if hydropower for each reservoir
        WRSYS(,2) – storage capacity at top of zone 2 if secondary reservoir, bottom of power pool if hydropower
        WRSYS(,3) – top of zone 1, storage capacity or top of power pool
        WRSYS(,4) – zone 2 releases factor or water-to-wire efficiency
        WRSYS(,5) – zone 1 release factor
        WRSYS(,6) – release made by reservoir to meet permitted diversion

WRTO(maxwr) - WRTO(wr) = ISO = counter and array index for variables entered on TO record [integer]

WSHED (maxwr) - drainage area ratio or other watershed parameter entered on SO record and used as multiplier of naturalized to determine water availability with watershed flow option [real]

X1,X2,Y1,Y2 – table values used for interpolation [real, LINEAR]

XRES – amount of target that is not available from streamflow [real, main program]
YEAR – current year in simulation [integer]

YRST – first year in simulation [integer]

ZONE – counts the number of reservoirs eligible to release from a storage zone [integer, RELEASE]

APPENDIX E
TABLES FORTRAN CODE INFORMATION

The main program of *TABLES* checks the identifier in the first field of each record of the input file, opens the required files, and calls the subroutines. The subroutines read the WRAP input and/or output files and develop the specified tables and data listings.

Input and Output Files

Unit	Filename	Type	Contents
1	root1.DAT	input	*TABLES* input file
2	root1.OUT	output	*TABLES* output file
3	root2.DAT	input	*WRAP-SIM* DAT file
4	root2.OUT	input	*WRAP-SIM* OUT file
5	root2.HRR	input	*WRAP-SIM* HRR file

Subroutines

TITLES - writes the title records on the cover page and at the top of each table.

CVPAGE - writes the cover page for the output tables.

SUMDAT - from a WRAP-SIM input file: writes a listing of selected records; develops a water rights summary; and sorts water rights in priority order by control point, use, type, or group.

RANKWR - called by subroutine SUMDAT to determine priority order of water rights read from *WRAP-SIM* input file.

SUMTAB - develops summary tables of monthly and/or annual WRAP-SIM output data for a control point, water right, reservoir, of the entire river basin (sum of control points).

TABLE - develops a table of monthly and annual data for a control point, water right, or reservoir. The data consists of either naturalized flows, regulated flows, unappropriated flows, streamflow depletions, diversions, diversion shortages, or reservoir storage.

RELIAB - develops a summary table of reliabilities and number of shortages for specified control points, water rights, or hydroelectric power reservoirs.

PERSTO - develops table of monthly end-of-period storages expressed as a percentage of capacity and reliability table for reservoir drawdowns similar to tables developed by RELIAB.

FLOWREC - develops flow records in *IN* or *TS* record format from naturalized flows, regulated flows, unappropriated flows, and/or streamflow depletions read from a *WRAP-SIM* output file.

SYSTAB -   develops monthly and annual tables of reservoir releases for water rights and water right groups.

FREQ -   develops frequency tables for naturalized flow, regulated flow, unappropriated flow, storage, and instream flow shortage.

Variables

Variables are grouped by type. Character variables are listed first, followed by integer variables, and then real variables.

Character Variables

CD - record identifier found in first four characters of each record of a TABLES input file.

CDOUT - record identifier on records output by subroutine FLOWREC.

CHAR- miscellaneous character variable.

CP, **USE**, **RES**, **GP** - temporary identifier variables.

CPID(maxcp) - control point identifiers.

GROUP(maxcp), **USID(maxuse)**, **CPID(maxcp)**, **RESDID(maxres)**, **WRID(maxwr)** - group identifiers listed for output, use identifiers, control point identifiers, reservoir identifiers, and water right identifiers in a *WRAP-SIM* input file.

IDEN(ID,30), **IDEN8(ID,30), IDEN16(ID,30)** - identifiers for control points (ID=0), water rights (ID=1), reservoirs (ID=2), or water right groups (ID=3).

IDEN(50,6) - identifiers for water rights associated with control points in subroutine HECIN.

INPUT - *TABLES* input file name.

JOBT - record identifier, same as CD, used in subroutine SUMDAT.

OUTPUT - *TABLES* output file name.

REC(15) - two-character identifiers of *WRAP-SIM* input data records to be listed, or not listed, by subroutine SELREC.

SYSRES(15) - identifiers of reservoirs listed for a water right in system file.

TITLE(5) - title records from a TABLES input file.

TITLE1, **TITLE2**, **TITLE3** - title records from a WRAP input file.

TMPRES(15) - temporary array of reservoir identifiers.

WRAP - first portion of the first line of a *WRAP-SIM* output file is reproduced on the *TABLES* cover page.

WRAPID - control point, water right, or reservoir identifier found in the WRAP output file.

WRAPIN - WRAP input file name.

WRAPOU - WRAP output file name.

Integer Variables

AVPERC - average percentage of active storage for all reservoirs listed by a 2PER record.

CAP(12,2) - top and bottom of active storage of reservoirs listed by a 2PER record.

COUNT - the number of either control points, water rights, or reservoirs for which to develop tables or to include in the tables.

COUNT1(maxcp) - control point counter.

COUNT2(6) - water right counter for the current control point.

CREC - record counter used to go to the next block of monthly data in reading the direct access WRAP output file. CREC = NWROUT + NCPTS + NREOUT

HEC - inputted parameter of whether streamflow records output by FLOWREC are grouped by years or by control point.

I - miscellaneous counter.

ID -indicated either a control point (ID=0), water right (ID=1), or reservoir (ID=2).

INCP(maxcp) - control point identifier on HEC IN record.

J - miscellaneous counter.

JTYPE1, **JTYPE2**, **JTYPE3** , **JTYPE4** - number of *TABLES* input records which specify job type 1, 2, 3, and 4 output, respectively.

JTOTAL - total number of records in *TABLES* input file.

K - miscellaneous counter.

KK - miscellaneous integer variable.

LOOP - counter for the computational loops repeated for each of the COUNT control points (ID=0), water rights (ID=1), or reservoirs (ID=2) as identified by IDEN (ID,LOOP).

MATCH - flag to determine if groups for input match groups for output.

MC(12,8) - the number of months (periods) for which the shortage equals or exceeds specified percentages of the target diversion amount.

MNAN - input parameter which specifies whether monthly or annual summary tables are to be developed.

MONTH - current month (1,2,3,...,12).

NUM - parameter used in several input records to specify the number of values of a variable to follow in the remaining fields of the input record.

N - number of periods (months) in the simulation. N = NYRS * NPRDS

NCPTS - number of control points included in the *WRAP-SIM* output file.

NGOUT - number of groups listed in a *WRAP-SIM* input file for output.

NPRDS - number of periods per year. NPRDS = 12 for a monthly time interval.

NREOUT - number of reservoirs included in the *WRAP-SIM* output file.

NRES - number of reservoirs included in a *WRAP-SIM* input file.

NRIGHT - number of rights included in a *WRAP-SIM* input file.

NTITLE - number of title records included in the *TABLES* input file.

NUSES - number of uses listed in a *WRAP-SIM* input file.

NUMCP - number of control points in a *WRAP-SIM* input file.

NWROUT - number of water rights included in the *WRAP-SIM* output file.

NYRS - number of years in the simulation.

PERC(12) - end-of-period storage as percentage of active storage capacity for reservoirs listed by a 2PER record.

PERIOD - current month.

PRHI, PRLO - highest and lowest priority numbers listed for a control point, type, use type, or water right group.

QREAD - flag to determine if the input data has been read in with a previous type 1 record.

RANK(maxwr) - listing of water right indices in priority order.

REC1 - record counter used to locate the first control point, water right, or reservoir/hydropower record to be read from the direct access WRAP output file.

RECORD - record counter for reading WRAP output file (unit=4).

RESDAT(maxwr) - storage capacities of all reservoirs listed in a WRAP input file.

RESFLAG - flag used to count reservoirs associated with a right.

RESNUM(maxwr) - reservoir location control point indices.

SCRNUM - flag variable to determine type of table to be built.

SKIP, LOOP, COUNT - counter variables used to move between records in a *WRAP-SIM* output file.

STO(12) - end-of-period storage for reservoirs listed by a 2PER record.

STOAVE(12) - average end-of-period storage for reservoirs listed by a 2PER record.

STOR - miscellaneous variable summing storage in *WRAP-SIM* input file.

SUMDIV, **SUMSTO** - summation of storage and annual diversion amounts listed for a control point, type, use type, or water right group in a *WRAP-SIM* input file.

SUMWRT, **SUMRES** - a total number of water rights and reservoirs listed for a control point, type, use type, or group as grouped on a 2SRT record.

TAMT, **TSHT** - temporary variables summing diversion amounts and shortages.

TOTDIV, **TOTSTO** - miscellaneous variables summing storage and annual diversion amounts in a *WRAP-SIM* input file.

TPRHI, **TPRLO** - highest and lowest priority numbers listed in a basin.

WRDAT(maxwr) - array of water right storage capacities and annual diversion amounts.

WRNUM(maxwr,6) - array of index numbers for reservoirs, control points, use type, etc. for each right listed in a WRAP-SIM input file.

YC(7) - the number of years for which the shortage equals or exceeds specified percentages of the target diversion amount.

YEAR - current year.

YRST - first year in the simulation.

YRLAST - last year in the simulation

<div align="center">

Real Variables

</div>

AMT - target diversion amount.

DATA(12) - monthly streamflow data.

INFAC - factor by which evaporation rates are multiplied.

F(12) - frequencies for which flows are computed with 2FRE record.

FQ(7) - the frequency computed for the flow QF(7) entered on 2FRQ record.

FLOW - streamflow data.

PERREL - period reliability.

MDATA(12) - monthly data printed by subroutine TABLES for each period (12 months of the year) for the current year. The data may be either naturalized flows (2NAT), unappropriated flows (2UNA), streamflow depletions (2DEP), shortages (2SHT), or storage (2STO).

- monthly data printed by subroutine SUMTAB in a summary table for a control point, water right, or reservoir (as specified by a 2SCP, 2SWR, 2SRE, or 2SGP input record, respectively) as follows:

	2SCP	2SWR	2SRE
naturalized streamflow	MDATA(8)		
return flow	MDATA(7)		
unappropriated flow	MDATA(6)		
regulated flow	MDATA(10)		
available streamflow		MDATA(6)	
streamflow depletion	MDATA(5)	MDATA(5)	MDATA(5)
storage	MDATA(4)	MDATA(4)	MDATA(4)
storage change		MDATA(10)	MDATA(10)
evaporation	MDATA(3)	MDATA(3)	MDATA(3)
permitted diversion	MDATA(2)	MDATA(2)	
actual diversion	MDATA(9)	MDATA(9)	
shortage	MDATA(1)	MDATA(1)	
releases from system		MDATA(7)	
power produced			MDATA(2)
power shortage			MDATA(1)
depletions into reservoir			MDATA(5)

releases into reservoir	MDATA(6)
depletions and releases into reservoir	MDATA(9)
releases through outlet works	MDATA(7)
releases from reservoir pool	MDATA(8)
total releases from reservoir	MDATA(11)

QF(7) - the flow entered on 2FRQ record for which frequencies FQ(7) are computed.

QFREQ(12) - flows computed for specified frequencies by 2FRE record.

RELMON(15) - monthly releases for a water right or water right group.

RELYR(15) - annual releases for a water right or water right group.

SAMT(7) - a specified percentage of the target diversion amount for the current month.

TMPREL(15) - temporary array of reservoir releases.

SYAMT(7) - a specified percentage of the annual target diversion amount.

SDATA(10) - sum of the monthly data, MDATA, for all the control points.

TOTAMT - total volume of the target diversion amount over the entire simulation period.

TOTSHT - total volume of the shortages over the entire simulation period.

VOLREL - volume reliability.

YDATA(10) - yearly total of the control point sums, SDATA.

YTOTAL - yearly total of monthly data, MDATA.

APPENDIX F
WRAP-HYD FORTRAN CODE INFORMATION

An *"Introduction to Appendices D, E, and F"* is provided at the beginning of Appendix D. The Fortran program *WRAP-HYD* is organized as follows.

- Module *COMVAR* (COMmon VARiables) located at the beginning of the program specifies the type and dimension limits for variables used in common by the main program and subroutines. Initial values of zero are specified for the variables.

- The main program controls the selection of tasks to be performed, calls the appropriate subroutines to perform each task, and writes the INF and EVA output files and certain data to the OUT output file.

- The subroutines perform specific computational and data management tasks. The majority of the subroutines are called one or more times from the main program. Subroutines are also called by other subroutines.

Input and Output Files

Unit	Filename	Type	Contents
1	Root1.DAT	Input	main input file
2	Root1.INF	Input	IN records
3	Root1.EVA	Input	EV records
4	Root1.DIS	Input	FD, FC, WP records
5	Root1. HYD	Input	IN and EV records
7	Root2.OUT	Output	all output not included in the following files
6	Root2.MSS	Output	error and trace messages
8	Root2.INF	Output	IN records with naturalized streamflows
9	Root2.EVA	Output	EV records with evaporation-precipitation
10	Root2.HYD	Output	IN and EV records combined in a single file

Subroutines

Consistency between *WRAP-HYD* and *WRAP-SIM* has been maintained to the extent possible. The following subroutines are essentially the same in both *WRAP-HYD* and *-SIM*: INFEVA, IACNP, FLDIST, CURNUM, and BISECT. The file unit numbers listed above are among the few minor differences in these subroutines between the two programs. Subroutines FILINI, CHECK, WRAPIN, INCREM, AVALB, are also common to both *WRAP-HYD* and *WRAP-SIM* but contain significant differences to accommodate the different purposes of the two programs. Subroutines INFEVA2, INFEVA3, EPADD, FLOWADJ, ADJUST, and EQUATION are unique to *WRAP-HYD*. All of the subroutines contained in *WRAP-HYD* are listed as follows.

FILEINI – file initiation routine called by main program to open input and output files.

CHECK – called by subroutine FILINI to check whether files exist.

WRAPIN – called by main program to read and organize the basic input data from the DAT file. Other subroutines also read other input data.

ERRMSS - writes an error message and terminates program execution if an IOSTAT error is detected in reading input data.

INFEVA – called by main program to read the streamflow *IN* and evaporation-precipitation depth *EV* records and arrange them in the same order as the control points.

INFEVA2 – called by main program to read *IN* and/or *EV* records and arrange them in the same order as the control points whenever the *IN* and/or *EV* records are in the optional format with records grouped by control points rather than by years.

INFEVA3 – called by main program to read the streamflows and/or evaporation-precipitation depths and arrange them in the same order as the control points whenever the streamflows and evaporation-precipitation depths are in a columnar table rather than *IN* and/or *EV* records.

HYDCHECK - called by main program to perform certain error checks.

EPADD – called by main program to combine sets of evaporation-precipitation data.

FLOWADJ – called by main program to adjust flows as specified by *AS* and *EQ* records.

ADJUST – called by subroutines FLOWADJ and EQUATION to adjust the flows at a control point and optionally at all downstream control points considering channel losses and options for handling negative flows.

EQUATION - called by subroutine FLOWADJ to adjust flows and evaporation-precipitation depths based on a regression equation.

INCREM – called by main program to determine negative incremental flows and to adjust the streamflows in accordance with the option specified on the *JC* record.

AVALB – called by subroutine INCREM in conjunction with negative incremental flow adjustment option 2.

IACNP – called by main program to read the flow distribution *DIS* file and determine the parameters for the total and/or incremental watersheds.

FLDIST – called by main program to distribute flows from gaged to ungaged control points. FLDIST also has a reservoir site runoff adjustment routine.

CURNUM – called by subroutine FLDIST to transfer flows using the modified NRCS CN method.

BISECT – called by subroutine CURNUM to solve the NRCS CN equation for P given Q using the iterative bisection method.

Parameters for Defining Array Dimensions

The arrays in the Fortran code are dimensioned to reserve memory space. Parameter statements are used to facilitate changing dimension limits. Many but not all of the array dimensions are set by the parameters listed below with their current values.

MAXCP = 300 maximum number of control points (*CP* records)

MAXRES = 250 maximum number of reservoirs

MAXMON = 12 number of periods per year

MAXTAB = 50 maximum number of storage-area tables (*SV/SA* records)

MAXGAG = 15 maximum number of upstream gages on *FD* records

MAXYRS = 125 maximum number of years

Definition of Variables

Subroutines INFEVA, IACNP, FLDIST, CURNUM, and BISECT are identical or almost identical in both *WRAP-HYD* and *WRAP-SIM*. Subroutines FILINI, CHECK, WRAPIN, INCREM, and AVALB are similar in the two programs. Many of the variables common to both programs and already listed in Appendix F are omitted in the following listing. However, some of key common variables are repeated in both appendices for convenience. Those variables unique to *WRAP-HYD* are all included in the list below.

Variables incorporated in *WRAP-HYD* are listed and defined as follows. Two items of information are provided in brackets following the description of each variable:

1. variable type (real, integer, character, logical)

2. location specified as either the main program or a specific subroutine. Locations are not specified for the variables included in module COMVAR which are used in common by the main program and/or multiple subroutines.

A, B, C – regression equation coefficients [real, EQUATION]

A1 – water surface area at the beginning of the month [real, FlOWADJ]

A2 – water surface at the end of the month [real, FlOWADJ]

ADJ(12) – adjustments to streamflows for each month of the year [real, FlOWADJ, ADJUST]

ADJINC – defines negative incremental inflow option to be used [integer]

ADJOUT – defines whether to write negative inflow adjustments file [integer]

ADJRUN - runoff volume from reservoir site used to compute streamflow adjustment [real, FlOWADJ]

ALL – all output files are opened writing over existing files with same filename [integer, FILINI, CHECK]

AREA – average reservoir water surface area during the month [real, FlOWADJ]

AS(5) – streamflow adjustment specifications read from the AS or EQ records [integer]

AS6 – factor to multiply the flow adjustments read in from the AS or EQ records [real]

AS7 – constant flow adjustment from AS record [real, FlOWADJ, ADJUST]

AUNIT – unit number controlling which file FlOWADJ reads [integer, FlOWADJ]

AVAMT – available streamflow at a control point [real]

BS – storage at the beginning of the month [real, FlOWADJ]

CAP – reservoir storage capacity from RS record [real, FlOWADJ]

CD – record identifier [character]

CHR – interactive user input to control program execution [character, CHECK]

CI(12) – constant monthly inflows/outflows from *CI* record [real, WRAPIN]

CIID – constant inflow control point identifier read from *CI* record [character, WRAPIN]

CINF(maxcp,maxmon) - flows read from *CI* records to be added to the naturalized streamflows [real]

CL(maxcp) - channel loss factors read from *CP* records [real]

CN(maxcp) - curve number for control point. [real, IACNP, FLDIST]

CN1 - curve number from WP record. [real, CurNum]

CNGAGE(maxcp) - CN of incremental gaged watershed. [real, IACNP, FLDIST]

CNUG(maxcp) - CN of incremental ungaged watershed. [real, IACNP, FLDIST]

COEF(maxcp,1) - COEF1 for flow distribution equation. [real, IACNP, FLDIST]

COEF(maxcp,2) - COEF2 for flow distribution equation. [real, IACNP, FLDIST]

COEF(maxcp,3) - COEF3 for flow distribution equation. [real, IACNP, FLDIST]

COEF1 - coefficient in flow distribution equation read from FD record. [real, IACNP, FLDIST]

COEF2 - coefficient in flow distribution equation read from FD record. [real, IACNP, FLDIST]

COEF3 - coefficient in flow distribution equation read from FD record. [real, IACNP, FLDIST]

CPDT(maxcp,2) – inflow and evaporation multiplication factors for each control point [real]

CPEP(4) - control point identifier for EP record control points [integer, EPADD]

CPEV(maxcp) - control point from which to repeat EV records. [character]

CPFLOW (maxcp,maxmon,5) – miscellaneous flow values at a control point each month [real]
      CPFLOW(,,1) – negative incremental
      CPFLOW(,,2) – unappropriated flow
      CPFLOW(,,3) – summation of streamflow depletion
      CPFLOW(,,4) – summation of flows returned
      CPFLOW(,,5) – summation of depletion minus summation of releases used in making release

CPID(maxcp,2) – control point and next downstream control point identifiers [character, common]

CPIN(maxcp) – control point identifiers [character]

CPNXT(maxcp) – indices of the next downstream control point for each control point [integer]

CPTID(maxcp) - control point identifier [character]

CSTOR - change in reservoir storage content [real, FLOWADJ]

DA(maxcp) - drainage area for control point. [real, IACNP, FLDIST]

DA1 - drainage area from WP record [real, IACNP, CURNUM]

DAGAGE(maxcp) - incremental drainage area of downstream gage [real, IACNP, FLDIST]

DAUG(maxcp) - incremental drainage are of ungaged site [real, IACNP, FLDIST]

DAUG1(maxcp) - drainage area of first upstream gage [real, IACNP, FLDIST]

DAUG2(maxcp) - drainage area of second upstream gage [real, IACNP, FLDIST]

DAUG3(maxcp) - drainage area of third upstream gage [real, IACNP, FLDIST]

DSG - downstream gage identifier on FD record [character]

EP(maxcp,maxyrs,maxmon) - monthly evaporation-precipitation depths at each control point for each month of each year [real]

EPA - monthly volume adjustment for evaporation-precipitation [real, FLOWADJ]

EPCOUNT - counter of number of EP records read [integer, EPADD]

EPADJ - evaporation-precipitation adjustment added to the streamflow [real, FlOWADJ]

EPID(4) - control point identifiers from EP record [character]

EPM(4) - multiplying factors from EP record [real]

ERROR – iteration convergence in hydropower computations [real]

EUNIT - unit number of file with evaporation-precipitation depths [integer, INFEVA]

EVAPR(MAXCP,MAXMON) – net evaporation rates at each control point each month of a year [real]

EVCFA – first storage-area coefficient for a reservoir [real]

EVCFB – second storage-area coefficient [real]

EVCFC – third storage-area coefficient [real]

EVCURV(maxtab,25) – storage-area tables for evaporation computations [real]

EWA(maxcp) - watershed area from *CP* record used to adjust net evaporation-precipitation for runoff from land covered by reservoir [real]

F(10) - file unit numbers to identify input and output files [integer]

FA(12) - an array holding the flow adjustments for each month of the year [real, FlOWADJ]

FACTOR – a multiplier AS6 from the AS record combined with delivery ratio (1-CL) used to model channel losses [real, ADJUST]

FANEG(maxcp) – negative value of flow adjustment used to carry adjustment to the next month for AS(5) options 3 and 4   [real, ADJUST]

FLOW(maxcp,maxyrs,maxmon) - the flow at each control point, for each month of each year [real]

ID - control point identifier on FD record [character]

IDSG(maxcp) - identifier for downstream gage [integer, IACNP, FLDIST]

IGAGE(maxcp,maxgag) - identifier for upstream gage [integer, IACNP, FLDIST]

INEV(maxcp) - CP record entry controlling omission of specified control points from the output [integer]

INFLOW(maxcp,maxmon) – inflow at each control point each month of a year [real]

INMETHOD(maxcp) - method for providing naturalized flows for control point [integer]

INWS - flag from CP record indicating whether parameters are for total or incremental watershed [integer]

IUNIT - unit number for input file with IN records [integer, INFEVA]

JC(6) - job control parameters which specify the file organization and negative incremental flow options [integer]

LOCNUM – index of control point [integer]

M - counter of the current month in the computations [integer, main, FLOWADJ, ADJUST]

MATCH – counter used in error checks to flag whether certain conditions occur [integer, WRAPIN, FLOWADJ]

MAXIT – maximum number of iteration [integer, BISECT]

MP(maxcp) - mean precipitation for control point. [real, IACNP, FLDIST]

MP1 - mean precipitation from WP record [real, IACNP, FLDIST]

MPGAGE(maxcp) - mean precipitation of incremental gaged watershed [real, IACNP, FLDIST]

MPUG(maxcp) - mean precipitation of incremental ungaged watershed [real, IACNP, FLDIST]

MT – current month of simulation [integer]
NAME – file name [character]

NCPTS – number of control points [integer]

NEGINC – parameter control selection of negative incremental flow adjustment to write [integer]

NEG(maxcp) - negative flow amount in one period is used to adjust flow in next period [real, ADJUST]

NEP - a counter for the number of EP records [integer]

NGAGE(maxcp,2) - number of gages located above the ungaged site[integer, IACNP, FLDIST]

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NPRDS – number of months in a year [integer]

NPT – index of next downstream control point [integer]

NRES – number of reservoirs in a basin [integer]

NSVSA - number of SV and SA records read [integer]

NTABLE - a counter of the number of storage-elevation tables [integer]

NWP - total number of WP records [integer, IACNP]

NWRTS - number of water rights in a basin [integer]

NYRS – number of years in a simulation [integer]

P – index used in character data manipulation [integer, main program, CHECK, FILINI]

PTBCNT – counter of storage-elevation tables read [integer, WRAPIN]

PYR – year being read [integer, INFEVA]

Q - streamflow [real, BISECT]

Q(maxcp,maxmon) - flows read from IN records [real]

Q1 - flow at a gaged site [real, CURNUM]

Q2 – flow computed at an ungaged site [real, CURNUM]

QE - EQ record specification of adjustment method option [integer]

QGAGE(maxcp) - incremental flows at gage [real, FLDIST]

QIN(maxmon) - flows read from IN records [real, FLDIST]

QTOTAL(maxcp,maxmon) - total cumulative flows at ungaged site [real, FLDIST]

QUG(maxcp,maxmon) - incremental flows at ungaged site [real, FLDIST]

REPEAT – identifier of control pint from which to repeat data [character, INFEVA]

RES,CP,USE,GP – temporary variables holding reservoir, control point, use, and group identifiers [character, WRAPIN]

RESAREA(maxtab, 25) - reservoir surface area–elevation data for the storage area tables [real]

RESID(maxres) – reservoir identifiers [character, WRAPIN]

RESNUM(maxres,4) – various indices pertaining to a reservoir [integer, WRAPIN]

      RESNUM(,1) – control point location index
      RESNUM(,2) – index of storage-area table
      RESNUM(,3) – flag to output reservoir
      RESNUM(,4) – index of storage-elevation table

ROOT – root of file name [character, FILINI]

ROOT – root of file name [character, main program]

ROOT – root of file name [character, FILINI]

RS5FLAG - flag of whether subroutine FLOWADJ has previously called subroutine IACNP [integer]

RS(6) - reservoir specifications for streamflow adjustments from RS record [integer, FlOWADJ]

RS7 - storage of a reservoir at the beginning of the first month from RS record [real, FlOWADJ]

RS8 – factor to multiply storage contents from RS record [real, FlOWADJ]

RUNOFF(maxcp,12) - runoff depth from reservoir site used to compute streamflow adjustment [real, FlOWADJ]

SC(12) - an array holding monthly storage contents of a reservoir from SC record [real]

SPILL - decrease in storage in the pool above the specified conservation capacity [integer, FLOWADJ]

STOR(maxtab,25) - an array holding reservoir storage-elevation data for the storage-area tables [real]

SUM – temporary cumulative sum of evaporation-precipitation depths [real, EPADD]

SUMQ – sum of flows at upstream gages [real, FLDIST]

TARA(24),TARB(24) – temporary arrays storing reservoir storage-flow, storage-area, and storage-elevation data [real, WRAPIN]

TOTAL(5) - totals written as last line of reservoir adjustments table [real, FlOWADJ]

TRY – flag to determine if flag exists [logical, CHECK]

TYPE – water right type [integer]

XADJ - intermediate flow volume adjustment value used in computing ADJ(M) [real, ADJUST]

XL - lower bound of the bisection equation [real, BISECT]

XRS(5) - multiplier factors of 1.0 or -1.0 used to implement addition versus subtraction specified by RS(5) on RS record [real, FLOWADJ]

XU – upper bound of the bisection equation [real, BISECT]

YEAR – current year in simulation [integer]

YR - the current year in the simulation [integer, main, FLOWADJ, ADJUST]

YR1 - integer counter of the first year of the flow adjustment [integer]

YRLAST - integer counter of the last year of the flow adjustment [integer]

YRST – first year in simulation [integer]

APPENDIX G
WRAP-SIM/TABLES EXAMPLES

Introduction to Appendices G and H

The twelve examples listed below are provided to illustrate the format and content of *WRAP* data sets. Input files for the examples are distributed with the *WRAP* programs. Hypothetical river basin systems are modeled. Simple rather than realistic numbers are used in the examples to facilitate manual tracking of the model computations. Simple expressions are also adopted for the alphanumeric identifiers of control points, reservoirs, and water rights. Any descriptive label may be used for these identifiers. Only a few of the many possible tables of simulation results are developed with *TABLES*. All of the types of tables are relevant for any of the examples. The selection of tables to present with each example was arbitrary. An effective way for users to familiarize themselves with *WRAP* is to add various features of interest to the examples, rerun the model, and analyze the results to confirm that the model behaves as expected.

Example	*SIM* or *HYD* Input Files	*SIM* or *HYD* Input Records	*TABLES* Input Records
WRAP-SIM and TABLES Examples Presented in Chapters 2 and 3			
1	DAT	T1,JD,CP,WR,ED,FO,EV,ED	
2	DAT	FO,UC,CP,IF,WR, WS,SV,SA,IN,EV.ED	2SCP,2REL,2FRE,2FRQ, 2STO,2REG,2UNA
3	DAT	T1,JD,CP,WR,ED,FO,EV,ED	
WRAP-SIM and TABLES Examples Presented in Appendix G			
4	DAT, INF, EVA, DIS	T1,T2,JD, UC,CP,IF,WR,WS, SV,SA,DI,IS,IP,IN,EV,FD,WP	PAGE,2REL, 2FRE,2FRQ
5	DAT,INF,EVA	JD,FO,RO,UC,RF,CP,CI, IF, WR,WS,SO,TO,ML,MS,IN,EV	2SCP, 2REL, 2PER
6	DAT	T1,JD,FO,RO,UC,CP,IF,WR, WS,OR,SV,SA,PV,PE,IN,EV	2REL,2FRE, 2REG,2UNA
7	DAT,INF	T1,T2,JD,FO,CP,IF, WR,WS,TO,TS, IN	2NAT,2REG,2STO, 2DIV,2SHT
8	DAT	T1,FO,JD,CP,WR,WS, SV,SA,EA,EF,IN,EV	2SWR,2SCP
WRAP-HYD Examples Presented in Appendix H			
9	DAT,INF,EVA	FO,JC,CP,EP,AS,FA,RS,SC,	
10	DAT,INF,EVA	FO,JC,CP,EP,AS,FA,RS,SC	
11	DAT,INF,EVA	FO,JC,CI,SV,SA,EP, AS,FA,RS,SC,ED	
12	DAT,INF,DIS,HYD	FO,JC,CP	

The input files for the twelve examples are distributed with the programs. Examples 1 and 2 are presented in Chapter 2. Example 3 is discussed in Chapter 3. Appendix G consists of Examples 4, 5, 6, 7, and 8 illustrating *WRAP-SIM* and *TABLES*. Four examples demonstrating use of *WRAP-HYD* are presented in Appendix H. *WRAP-HYD* and *WRAP-SIM* both contain several of the same computational routines. Thus, some of the *WRAP-HYD* options, such as transferring streamflows from gaged to ungaged sites, illustrated by the *WRAP-HYD* examples in Appendix J are also pertinent to *WRAP-SIM* and vice versa.

WRAP-SIM and TABLES Examples

The *WRAP-SIM* and *TABLES* input and output data for Example 2 are included in the presentation in Chapter 2. The input files for Examples 1 and 3 are included on computer disk with the other examples. However, the discussion of Examples 1 and 3 in Chapters 2 and 3 focus on specific aspects of the simulation computations and do not include actual data files. Example 1 addresses fundamental water rights loop computational algorithms in *WRAP-SIM*. Example 3 focuses specifically on negative incremental flow adjustments. The set of example input files distributed with the model also includes a modified version of Example 3 revised to include synthesized streamflows. All of the *WRAP-SIM* examples include the required *T1*, *JD*, *CP*, *WR or IF*, *ED*, and *IN* records. Examples 1 and 3 are limited to these basic types of records along with *FO* and *EV* records. The other examples include various other input records and associated modeling features.

Example 4

Default input and output files are used in Example 4; thus, a *FO* record is not required. Input data files are printed on the following pages. Filenames are exam4.DAT, exam4.INF, exam4.EVA, and exam4.DIS. *WRAP-SIM* creates output files with filenames exam4.OUT and exam4.MSS. Neither is reproduced here. The message file (filename exam4.MSS) provides the trace messages shown in the *Users Manual* indicating the simulation progressed to a normal completion. *TABLES* reads the file exam4.OUT and organizes the simulation into selected tables. *TABLES* input and output files (filenames tab4.DAT and tab4.OUT) are reproduced here following the *WRAP-SIM* input. The spatial configuration of the river basin system is shown in the schematic on the next page.

Hydrology for Example 4

A 3-year 1996-1998 hydrologic period-of-analysis is adopted. A 30 to 80 year period-of-analysis would be more representative of actual modeling applications, but we need to keep the examples small. Naturalized streamflows, in acre-feet/month, are provided as input on *IN* records for control points CP-2, CP-3, and CP-5. Naturalized streamflows at CP-1 are synthesized by transferring flows from CP-2 using the modified NRCS CN method (Equations 6-16 and 6-17). Flows at CP-4 are synthesized by applying the drainage area ratio method with channel losses (Equation 6-11) to the incremental flows at CP-5 from the subwatershed below CP-2 and CP-3. Channel loss factors (Equation 6-3) of 0.10, 0.12, and 0.15, respectively, are entered on the *CP* records for CP-2, CP-3, and CP-4.

Net evaporation-precipitation depths in inches are provided on *EV* records for CP-2. These depths are converted to feet by the multiplier factor in field 5 of the *CP* record. Net

evaporation-precipitation depths for CP-2 are repeated for CP-3 by *CP* record field 7. Since there are no reservoirs at CP-1, CP-4, and CP-5, *NONE* is entered in *CP* record field 7.
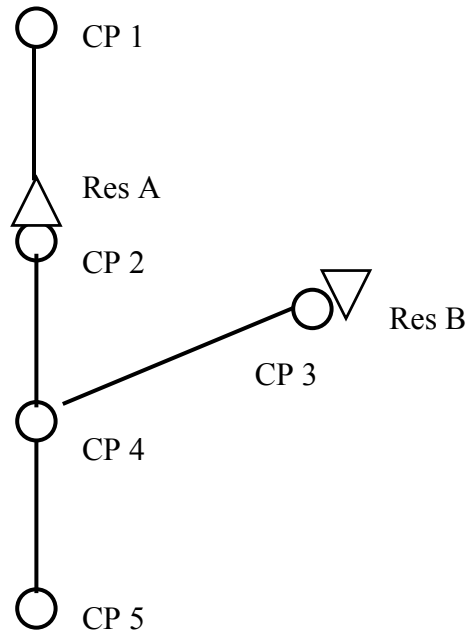
System Schematic for Example 4

Water Rights for Example 4

Information for the seven water rights is tabulated below.

Water Right	Water Right Owner	Location	Reservoir	Priority Number	Refilling Capacity (acre-feet)	Permitted Diversion (ac-ft/yr.)	Return Flow Factor	Instream Flow Requirement
WR-1	Mr. J. W. Smith	CP-1	-	1965	-	1,200	0.2	-
WR-2	Municipal District	CP-2	Res A	9999	80,000	-0-	-	-
WR-3	Irrigation District	CP-3	Res B	1975	30,000	42,000	0.1	-
WR-4	Irrigation District	CP-3	Res B	8888	40,000	40,000	0.35	-
WR-5	City of Jonesville	CP-4	Res A	1984	-0-	26,000	-	-
WR-6	Elm City	CP-5	Res A	1952	-0-	18,000	-	-
WR-7	State of Texas	CP-5	-	1111	-	-	-	12,000

Water right 1 is a run-of-river (no reservoir storage) irrigation diversion of 1,200 acre-feet/year at CP-1, distributed seasonally (*UC* records) as follows: 240 ac-ft in May and August and 360 ac-ft in June and July. Twenty percent of the water diverted each month is returned at CP-2. The priority number of 1965 represents the effective date of the water right permit.

Water right 3 includes a 42,000 ac-ft/year diversion from Reservoir B and filling storage to a capacity of 30,000 ac-ft with a priority number of 1975. Water right 4 consists of filling reservoir B to its full capacity of 40,000 ac-ft with a priority junior to all diversion rights but senior to filling storage in Reservoir A.

Water rights 5 and 6 are diversions for municipal use by the cities of Jonesville and Elm City from streamflows at CP-4 and CP-5, respectively, supplemented as necessary by releases from Reservoir A. Their water right permits have effective dates of 1984 and 1952 which set their priorities. Reservoir A is refilled by water right 2 with a priority junior to all other rights, represented by a priority number of 9999 which is larger than the priority numbers of all other rights but otherwise arbitrary. Any time the storage content of Reservoir A drops to 20,000 ac-ft (25% of capacity), a municipal demand management plan is implemented which reduces the diversion requirements to 80% of normal.

Water right 7 is an instream flow target at CP-5 that varies as a function of total system storage and is modeled using the drought index feature (*DI/IS/IS* records). The instream flow target varies linearly from 500 ac-ft/month (6,000 ac-ft/year) when both reservoirs are empty to 1,000 ac-ft/month (12,000 ac-ft/year) when the total storage is 60,000 ac-ft (50% of capacity). If the total storage content is between 60,000 and 108,000 ac-ft, the instream flow requirement is set at 1,000 ac-ft/month. If storage rises above 108,000 ac-ft, the flow target increases to 1,250 ac-ft/month. The drought index is as follows.

Total Storage Content of Reservoirs A and B (acre-feet)	Instream Flow (ac-ft/month)	Instream Flow as a Percentage of 1,000 ac-ft/month
0	500	50%
60,000	1,000	100%
60,000 to 108,000	1,000	100%
108,001 to 120,000	1,250	125%

WRAP-SIM DAT File for Example 4

```
T1  Example 4 -  WRAP-SIM Input File Exam4.DAT
T2  Example 4 from Appendix G of WRAP Reference Manual
**
**              Fixed-Width Fields and Columns
**   2 !    3 !    4 !    5 !    6 !    7 !    8 !    9 !   10 !   11 !   12
!
** 3-8 !  9-16 ! 17-24 ! 25-32 ! 33-40 ! 41-48 ! 49-56 ! 57-64 ! 65-72 ! 73-80 ! 81-88
!
**
JD    3   1996        1      -1      -1
```

```
**
**        Water Use Coefficients
UC    mun    0.06    0.06    0.06    0.06    0.06    0.10
UC           0.12    0.12    0.11    0.10    0.09    0.06
UC    irr    0.00    0.00    0.00    0.00    0.20    0.30
UC           0.30    0.20    0.00    0.00    0.00    0.00
**
**        Control Points
CP  CP-1    CP-2                         4           NONE
CP  CP-2    CP-4        0.083333         0                                   0.10
CP  CP-3    CP-4                         0           CP-2                    0.12
CP  CP-4    CP-5                         6           NONE                    0.15
CP  CP-5     OUT                         0           NONE
**
**        Water Rights
WR  CP-1    1200    irr    1965              0.2                 WR-1
**
WR  CP-2                   9999                                  WR-2
WS Res A   80000
**
WR  CP-3   42000    irr    1975              0.1                 WR-3
WS Res B   30000
WR  CP-3                   8888                                  WR-4
WS Res B   40000
**
WR  CP-4   26000    mun    1984              0.35              2 WR-5
WS Res A       0
**
WR  CP-5   18000    mun    1952                                2 WR-6
WS Res A       0
**
IF  CP-5   12000               0                       1    WR-7
**
**        Reservoir Storage Volume versus Surface Area Tables
SV Res A        0     825    2980    8640   22100   42700   73700   89600
SA              0     112     327     920    1760    2480    3750    4930
**
SV Res B        0     740    2680    7780   19800   38400   52900
SA              0     100     298     832    1580    2230    2690
**
**        Drought Indices
DI     1      -1
IS     5       0   60000  108000  108001  120000
IP            50     100     100     120     120
**
DI     2       1   Res A
IS     4       0   20000   20001  800000
IP            80      80     100     100
ED
```

WRAP-SIM FLO File for Example 4

```
**    WRAP-SIM Input File Exam4.FLO
**    Example 4 from Appendix G of WRAP Reference Manual
**    Naturalized Monthly Streamflows in acre-feet
**
IN  CP-2    1996    10800    12500    8100    7620    9610    1200     850    2540
9520    1850    1760    7200
IN  CP-3    1996    5200     6280     3750    3970    4450     750    1090    2160
4670     915     850    3490
IN  CP-5    1996    19400    24600    1420   15200   18400    2640    2290    6240
21800    3780    3720   13900
**
IN  CP-2    1997    6250     8140     4190    7280    6930    1390     725     545
942     1890    4910    5740
IN  CP-3    1997    2180     4320     3760    2350    3760     870     915     296
1020    2250    4870    3190
IN  CP-5    1997    11200   17800     7690   14500   15400    2930    1910    1290
2300    5190    12800   13700
**
IN  CP-2    1998    7680     6590     5570    5230    6180    1280    1670    1050
7890    8670    6210    5360
IN  CP-3    1998    3820     3540     2190    2310    3290     657     845     840
3970    4230    3540    2870
IN  CP-5    1998    15400   13900    18300    9780   12600    2560    3420    2650
15400   17400    12700   11800
```

WRAP-SIM EVA File for Example 4

```
**    WRAP-SIM Input File Exam4.EVA
**    Example 4 from Appendix G of WRAP Reference Manual
**    Net Evaporation-Precipitation Rates in Inches
**
EV  CP-2    1996    3.2    2.8    3.1   -1.6   -3.7    1.9    4.3    3.9    2.5    1.9
1.6    2.9
EV  CP-2    1997    2.5    1.7   -4.9   -0.9   -2.1    0.7    3.5    2.8    3.1    2.5
0.9    2.6
EV  CP-2    1998    2.9    2.1   -1.5   -2.8   -2.6   -0.2    2.7   -1.4    2.2    2.1
2.0    1.9
```

WRAP-SIM DIS File for Example 4

```
**   Example 4 -  WRAP-SIM Input File Exam4.DIS
**   Example 4 from Appendix G of Reference Manual
**
**   Flow Distribution Information
**
FD  CP-4    CP-5        2    CP-2     CP-3
FD  CP-1    CP-2
**
WP  CP-1    225      74      31
WP  CP-2    398      69      31
WP  CP-3    194
WP  CP-4    650
WP  CP-5    715
ED
```

TABLES Input File for Example 4

```
COMM    TABLES Input File Tab4.DAT
COMM    Example 4 from Appendix G
PAGE
2REL
2FRE    1
2FRE    2
2FRE    3
2FRE    4   2    CP-2    CP-3
2FRQ    3   7    CP-5 200,2000,5000,8000,10000,15000,20000,
ENDF
```

TABLES Output File for Example 4

```
    ****************************************************
    **                                                **
    **        Water Rights Analysis Package (WRAP)    **
    **                                                **
    **        Program WRAP-SIM (July 2001 Version)    **
    **        Program TABLES   (July 2001 Version)    **
    **                                                **
    ****************************************************


    Date: 09-JUL-01    Time: 11:57:20



    Title records from program WRAP-SIM output file:

      Example 4 -  WRAP-SIM Input File Exam4.DAT
      Example 4 from Appendix G of WRAP Reference/Users Manual



    The program WRAP-SIM output file contains simulation results for:
         7 water rights
         5 control points
         0 reservoirs
    for a period-of-analysis of  3 years beginning in 1996.


    The program TABLES input file contains 10 records including:
         0 Job Type 1 Records
         6 Job Type 2 Records
         0 JOB Type 3 Records


    Program TABLES input file name:   tab4.DAT
    Program TABLES output file name:  tab4.OUT
    Program WRAP-SIM output file name: exam4.OUT
```

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

```
--------------------------------------------------------------------------------------
-----------------------------------------
         TARGET       MEAN    *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS
+++++++++|---------- PERCENTAGE OF YEARS ----------
NAME     DIVERSION    SHORTAGE PERIOD VOLUME|   WITH DIVERSIONS EQUALING OR EXCEEDING
PERCENTAGE OF TARGET DIVERSION AMOUNT
        (AC-FT/YR)  (AC-FT/YR)   (%)     (%) | 100%   95%   90%   75%   50%   25%  >0%
| 100%   98%   95%   90%   75%   50%   >0%
--------------------------------------------------------------------------------------
-----------------------------------------
  CP-1     1200.0       710.1   33.33  40.83| 33.3  33.3  41.7  41.7  41.7  50.0
100.0|  0.0   0.0   0.0   0.0   0.0   0.0 100.0
  CP-2        0.0         0.0   There are no diversions at this control point.
```

```
  CP-3      42000.0       8342.0     66.67  80.14| 66.7  66.7  66.7  75.0  75.0  83.3
100.0| 33.3  33.3  33.3  33.3  66.7 100.0 100.0
  CP-4      26000.0       9209.0     61.11  64.58| 61.1  61.1  61.1  63.9  63.9  80.6
100.0|  0.0   0.0   0.0   0.0   0.0 100.0 100.0
  CP-5      18000.0       2213.3     77.78  87.70| 77.8  77.8  77.8  86.1  91.7  94.4
100.0|  0.0   0.0  33.3  33.3 100.0 100.0 100.0
--------------------------------------------------------------------------------
------------------------------------------
 Total     87200.0      20474.4            76.52
------------------------------------------
```

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

```
----------------------------------------------------------------------------------
----------------------------------
CONTROL          STANDARD      PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING
VALUES SHOWN IN THE TABLE
 POINT    MEAN DEVIATION 100%      99%      98%      95%      90%      75%      60%
50%     40%     25%     10%   MAXIMUM
----------------------------------------------------------------------------------
----------------------------------
  CP-1    4513.4 2479.0   889.0   952.9  1016.9  1161.4  1329.4  1982.9   4519.
5033.   5548.   6421.   7732.   9745.
  CP-2    5162.8 3313.8   545.0   609.8   674.6   825.0  1006.8  1760.0   5038.
5740.   6454.   7680.   9556.  12500.
  CP-3    2762.7 1572.4   296.0   426.0   555.9   731.4   843.0  1020.0   2274.
3190.   3540.   3970.   4750.   6280.
  CP-4    9325.0 5734.9  1081.7  1339.6  1597.6  2073.6  2233.6  3213.8   8275.
11203.  11913.  13600.  17079.  22023.
  CP-5   10444.7 6772.7  1290.0  1336.8  1383.6  1812.0  2296.0  3420.0   8526.
12600.  13820.  15400.  18800.  24600.
----------------------------------------------------------------------------------
----------------------------------
```

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

```
----------------------------------------------------------------------------------
----------------------------------
CONTROL          STANDARD      PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING
VALUES SHOWN IN THE TABLE
 POINT    MEAN DEVIATION 100%      99%      98%      95%      90%      75%      60%
50%     40%     25%     10%   MAXIMUM
----------------------------------------------------------------------------------
----------------------------------
  CP-1    4472.6 2486.7   889.0   952.9  1016.9  1161.4  1329.4  1982.9   4519.
5033.   5548.   6421.   7600.   9745.
  CP-2    4723.1 3214.9   545.0   608.6   672.2   724.3   905.2  1350.3   4746.
5507.   6167.   7098.   8730.  11516.
  CP-3     605.6 1425.8     0.0     0.0     0.0     0.0     0.0     0.0      0.
0.      0.    401.   3712.   5748.
  CP-4    5912.2 4351.9   939.7   979.5  1019.3  1059.0  1481.8  1961.8   4888.
6088.   6599.   8403.  11929.  19109.
  CP-5    6718.0 5632.3  1000.0  1000.0  1000.0  1000.0  1000.0  1000.0   3632.
7037.   8486.  11124.  14946.  21589.
----------------------------------------------------------------------------------
----------------------------------
```

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

```
----------------------------------------------------------------------------------
----------------------------------
CONTROL          STANDARD      PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING
VALUES SHOWN IN THE TABLE
 POINT    MEAN DEVIATION 100%      99%      98%      95%      90%      75%      60%
50%     40%     25%     10%   MAXIMUM
```

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```
--------------------------------------------------------------------------------
----------------------------------
  CP-1    3550.5  3177.5     0.0     0.0     0.0     0.0     0.0     0.0   1989.
4826.   5372.   6299.   7281.   9745.
  CP-2    4032.4  3697.7     0.0     0.0     0.0     0.0     0.0     0.0   2177.
5371.   5999.   6902.   8629.  11516.
  CP-3     391.5  1333.1     0.0     0.0     0.0     0.0     0.0     0.0      0.
0.      0.      0.   1515.   5748.
  CP-4    5074.0  5072.4     0.0     0.0     0.0     0.0     0.0     0.0   2200.
5704.   6349.   8403.  11929.  19109.
  CP-5    5684.7  5604.9     0.0     0.0     0.0     0.0     0.0     0.0   2632.
6037.   7486.  10124.  13826.  20389.
--------------------------------------------------------------------------------
----------------------------------
```

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

```
--------------------------------------------------------------------------------
----------------------------------
CONTROL          STANDARD      PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING
VALUES SHOWN IN THE TABLE
 POINT      MEAN DEVIATION  100%      99%      98%      95%      90%      75%      60%
50%     40%     25%     10%  MAXIMUM
--------------------------------------------------------------------------------
----------------------------------
  CP-2    79434.   1030.  76117.  76276.  76435.  77386.  77773.  79336.  80000.
80000.  80000.  80000.  80000.  80000.
  CP-3    15570.  12262.     12.     15.     19.     23.    399.   7077.  11232.
13637.  16764.  23198.  39648.  40000.
--------------------------------------------------------------------------------
----------------------------------
```

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS FOR CONTROL POINT CP-5

```
--------------------------------------------------------------------------------
------------------------------------------
   FLOW    FREQ(%)    FLOW    FREQ(%)    FLOW    FREQ(%)    FLOW    FREQ(%)    FLOW
FREQ(%)     FLOW    FREQ(%)    FLOW    FREQ(%)
--------------------------------------------------------------------------------
------------------------------------------
   200.0    61.11    2000.0    61.11    5000.0    55.56    8000.0    33.33   10000.0
25.00    15000.0     5.56   20000.0     2.78
--------------------------------------------------------------------------------
------------------------------------------
```

Example 5

The *WRAP-SIM* input data for Example 5 are stored in files, with filenames exam5.DAT, exam5.FLO, and exam5.EVA, which are printed on the following pages. *TABLES* input and output files (filenames tab5.dat and tab5.out) are also shown. A two-year 1990-1991 hydrologic period-of-analysis is adopted. A system schematic is provided below. Control point CP 5 is located in a separate river basin from the other control points. Very simple numbers are used in this example to facilitate manual tracking of the simulation computations. Comment ** records inserted in the exam5.DAT file describe the various groups of records.
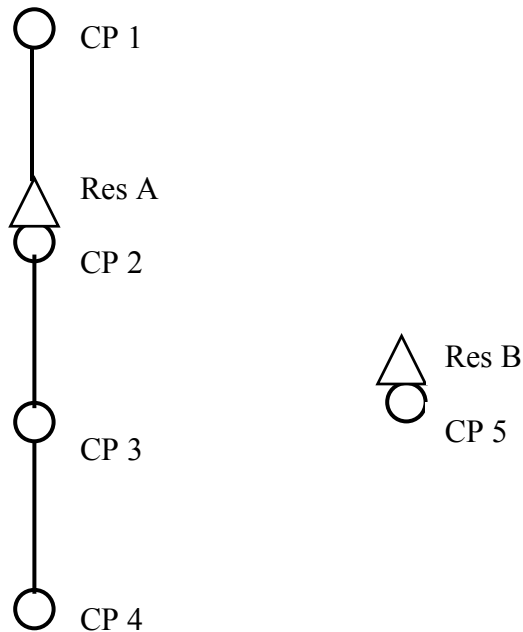
System Schematic for Example 5

WRAP-SIM **DAT File for Example 5**

```
T1  WRAP-SIM Input File Exam5.DAT
T2  Example 5 from Appendix G of WRAP Reference Manual
**
**  The default DAT, INF, EVA input files and OUT and MSS output files
**  are used, but there is no DIS file.
**
FO                  -1
JD    2    1990      1      -1      -1
**
**  The -1's on the JD record result in output for all water rights and control
**  points.  The following RO record results in output for the two reservoirs.
**
RO    2   Res A   Res B
**
**  Constant use factors distribute an annual diversion uniformly over the year.
**  Since this is the model default, the following UC records are not required.
**
UC const      1      1      1      1      1      1
UC            1      1      1      1      1      1
**
```

```
**  RF records allow return flow factors to vary over the 12 months of the year.
**
RF rflow     0.2      0.2      0.2      0.0      0.0      0.0
RF           0.3      0.3      0.3     0.25     0.25     0.25
**
**  Loss CL factors of 0.25 and 0.3 are input in field 10 of the CP records
**  for CP1 and CP2.  The watershed area of 1,000 acres entered in field 9
**  for CP2 is used in determining the adjusted net evap-precip for RES1.
**  Field 8 indicates there are no EV records for CP1, CP3, and CP4.
**
CP   CP1     CP2                                    NONE            0.25
CP   CP2     CP3                                          1000.     0.30
CP   CP3     CP4                                    none
CP   CP4     OUT                                    zero
CP   CP5     OUT                                          CP2
**
**  An inflow of 20 acre-feet/month enters the river system at CP1.
**
CI   CP1      20       20       20       20       20       20
CI            20       20       20       20       20       20
**
**  Instream flow requirement IF1 sets a minimmum regulated flow target of
**  70 ac-ft/month at CP3.  With a priority number of 1900, IF1 is senior
**  to all of the other rights except IF4.
**
IF   CP3     840    const    1900       2         IF1
**
**  Return flow options 4 and 1 are adopted for water rights WR1 and WR2a.
**
WR   CP1     360    const    1985       3    rflow             WR1
WR   CP2     840    const    1980             0.2              WR2a
WS Res A     200     0.1       1        0.             400
**
**  WR2a refills storage in reservoir Res A to 200 ac-ft with a 1980 priority.
**  WR2b fills Res A to full capacity of 500 ac-ft, subject to limits imposed
**  by the MS records, with a priority junior to all other rights.
**
WR   CP2       0    const    3000                             WR2b
WS Res A     500                                 400
**
**  Releases from Res A are made, if necessary, to meet a instream flow target
**  of 30 ac-ft/month set by IF2.  RES1 passes inflows but does not release
**  from storage for the IF1 target of 70 ac-ft/month.
**
IF   CP3     360    const    2000    2            IF2
WS Res A     500                                 400
**
**  The final unappropriated flows are based on the IF1 instream flow
**  requirement of 70 ac-ft/month at CP3, which is repeated as IF3 with a
**  priority junior to all rights except the WR2b reservoir refilling right.
**
IF   CP3     840    const    2100       2         IF3
**
**  A minimum flow at CP5 must be maintained of 50 percent of the CP5 naturalized
**  streamflow. The minimum flow at CP5 must also be at least 2 percent of the
**  naturalized flow at CP4. These combined rights are the most senior in the model.
**
IF   CP5                     1800       2         IF4
TO    1     0.5                               CP5                        CONT
TO    2     0.02    MAX                       CP4
**
**  Res B is located at CP5 and is filled from streamflow at CP4 as well as CP5.
**  WR3a includes both storage in Res B and a 20 ac-ft/month diversion at CP5.
**  WR3b allows filling of Res B at CP5 by depleting streamflows from CP4.
**  The CP4 streamflow depletion has both monthly and annual limits.
**

WR   CP5     240    const    8888                             WR3a
WS Res B     100     0.1       1      0.0
WR   CP5       0    const    9999                             WR3b
WS Res B     100
SO                   350      CP4
ML    5        0       0       5       15       15      200      200      200      200      200      200
```

```
**
**  A seasonal rule curve operating plan is in effect for reservoir Res A.
**  Storage is limited to 400 ac-ft from October through March and limited
**  to 500 ac-ft from April through September.
**
MS Res A  400,400,400,500,500,500,500,500,500,400,400,400,
**
**  The hydrology (IN and EV) records are in files Exam5.INF and Exam5.EVA.
**
ED
```

WRAP-SIM FLO File for Example 5

```
**    WRAP-SIM Input File Exam5.FLO
**    Example 5 from Appendix G of WRAP Reference Manual
**    Naturalized Streamflows
**
IN    CP1    1990      60       60       60       80       80       80       30       30
30       90       90       90
IN    CP2    1990     100      100      100      120      120      120       50       50
50      150      150      150
IN    CP3    1990     130      130      130      160      160      160       80       80
80      200      200      200
IN    CP4    1990     190      190      190      220      220      220      140      140
140      260      260      260
IN    CP5    1990      10       10       10       10       10       10       10       10
10       10       10       10
**
IN    CP1    1991      60       60       60        0        0        0      120      120
120       60       60       60
IN    CP2    1991     100      100      100        0        0        0      200      200
200      100      100      100
IN    CP3    1991     130      130      130        0        0        0      260      260
260      130      130      130
IN    CP4    1991     190      190      190       60       60       60      320      320
320      190      190      190
IN    CP5    1991      10       10       10       10       10       10       10       10
10       10       10       10
```

WRAP-SIM EVA File for Example 5

```
**  WRAP-SIM Input File Exam5.EVA
**  Example 5 from Appendix G of WRAP Reference Manual
**  Net Evaporation-Precipitation Rates
**
EV    CP2    1990     0.5      0.5      0.5      0.5      0.5      0.5      0.5      0.5
0.5      0.5      0.5      0.5
EV    CP2    1991     0.5      0.5      0.5      0.5      0.5      0.5      0.5      0.5
0.5      0.5      0.5      0.5
```

TABLES Input File for Example 5

```
COMM   TABLES Input File Tab5.dat
```

```
COMM    Example 5 from Appendix G of WRAP Reference Manual
2SCP
2REL       1
2PER   2   Res A    Res B
2PER          500      100
ENDF
```

TABLES Output File for Example 5

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP1

```
--------------------------------------------------------------------------------
--------------------------------------------
            NATURALIZED      RETURN   STREAMFLOW  UNAPPROPRIATED   EOP
REGULATED       ACTUAL     DIVERSION
YEAR          STREAMFLOW      FLOW      DEPLETION       FLOW       STORAGE
EVAPORATION   STREAMFLOW   DIVERSION     SHORTAGE
            (ACRE-FEET)     (AC-FT)  (ACRE-FEET)   (ACRE-FEET)    (AC-FT)   (ACRE-
FEET)      (AC-FT)      (AC-FT)       (AC-FT)
--------------------------------------------------------------------------------
--------------------------------------------
1990              780.0        0.0       350.1         96.2         0.0
0.0        669.9       350.1           9.9
1991              720.0        0.0       270.0         84.0         0.0
0.0        690.0       270.0          90.0
MEAN              750.0        0.0       310.0         90.1         0.0
0.0        679.9       310.0          50.0
--------------------------------------------------------------------------------
--------------------------------------------
```

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP2

```
--------------------------------------------------------------------------------
--------------------------------------------
            NATURALIZED      RETURN   STREAMFLOW  UNAPPROPRIATED   EOP
REGULATED       ACTUAL     DIVERSION
YEAR          STREAMFLOW      FLOW      DEPLETION       FLOW       STORAGE
EVAPORATION   STREAMFLOW   DIVERSION     SHORTAGE
            (ACRE-FEET)     (AC-FT)  (ACRE-FEET)   (ACRE-FEET)    (AC-FT)   (ACRE-
FEET)      (AC-FT)      (AC-FT)       (AC-FT)
--------------------------------------------------------------------------------
--------------------------------------------
1990             1260.0       64.5      1122.8         72.1       400.0
282.6       119.2       840.0           0.0
1991             1200.0       67.5      1168.5        108.4       400.0
251.4       153.4       840.0           0.0
MEAN             1230.0       66.0      1145.6         90.3       400.0
267.0       136.3       840.0           0.0
--------------------------------------------------------------------------------
--------------------------------------------
```

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP3

```
--------------------------------------------------------------------------------
--------------------------------------------
            NATURALIZED      RETURN   STREAMFLOW  UNAPPROPRIATED   EOP
REGULATED       ACTUAL     DIVERSION
YEAR          STREAMFLOW      FLOW      DEPLETION       FLOW       STORAGE
EVAPORATION   STREAMFLOW   DIVERSION     SHORTAGE
            (ACRE-FEET)     (AC-FT)  (ACRE-FEET)   (ACRE-FEET)    (AC-FT)   (ACRE-
FEET)      (AC-FT)      (AC-FT)       (AC-FT)
```

```
------------------------------------------------------------------------------
--------------------------------------------
1990            1710.0        168.0          0.0      239.4          0.0
0.0    1079.4          0.0          0.0
1991            1560.0        168.0          0.0      291.7          0.0
0.0     995.2          0.0          0.0
MEAN            1635.0        168.0          0.0      265.6          0.0
0.0    1037.3          0.0          0.0
------------------------------------------------------------------------------
--------------------------------------------
```

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP4

```
------------------------------------------------------------------------------
--------------------------------------------
            NATURALIZED      RETURN   STREAMFLOW  UNAPPROPRIATED   EOP
REGULATED    ACTUAL     DIVERSION
YEAR        STREAMFLOW      FLOW      DEPLETION       FLOW        STORAGE
EVAPORATION  STREAMFLOW   DIVERSION    SHORTAGE
            (ACRE-FEET)    (AC-FT)   (ACRE-FEET)   (ACRE-FEET)    (AC-FT)   (ACRE-
FEET)     (AC-FT)     (AC-FT)      (AC-FT)
------------------------------------------------------------------------------
--------------------------------------------
1990            2430.0          0.0      226.5     1573.1          0.0
0.0    1573.1          0.0          0.0
1991            2280.0          0.0      230.2     1485.4          0.0
0.0    1485.4          0.0          0.0
MEAN            2355.0          0.0      228.4     1529.3          0.0
0.0    1529.3          0.0          0.0
------------------------------------------------------------------------------
--------------------------------------------
```

ANNUAL SUMMARY TABLE FOR CONTROL POINT CP5

```
------------------------------------------------------------------------------
--------------------------------------------
            NATURALIZED      RETURN   STREAMFLOW  UNAPPROPRIATED   EOP
REGULATED    ACTUAL     DIVERSION
YEAR        STREAMFLOW      FLOW      DEPLETION       FLOW        STORAGE
EVAPORATION  STREAMFLOW   DIVERSION    SHORTAGE
            (ACRE-FEET)    (AC-FT)   (ACRE-FEET)   (ACRE-FEET)    (AC-FT)   (ACRE-
FEET)     (AC-FT)     (AC-FT)      (AC-FT)
------------------------------------------------------------------------------
--------------------------------------------
1990             120.0          0.0       58.8        0.0        100.0
45.2      61.2      240.0          0.0
1991             120.0          0.0       55.1        0.0        100.0
45.2      64.9      240.0          0.0
MEAN             120.0          0.0       57.0        0.0        100.0
45.2      63.0      240.0          0.0
------------------------------------------------------------------------------
--------------------------------------------
```

RELIABILITY SUMMARY FOR SELECTED WATER RIGHTS

```
------------------------------------------------------------------------------
-------------------------------------------
         TARGET      MEAN    *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS
+++++++++|---------- PERCENTAGE OF YEARS ----------
NAME     DIVERSION   SHORTAGE  PERIOD VOLUME|  WITH DIVERSIONS EQUALING OR EXCEEDING
PERCENTAGE OF TARGET DIVERSION AMOUNT
        (AC-FT/YR)  (AC-FT/YR)   (%)     (%) | 100%   95%   90%   75%   50%   25%   >0%
| 100%   98%   95%   90%   75%   50%   >0%
------------------------------------------------------------------------------
-------------------------------------------
WR2a       840.0       0.0  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0
100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
WR1        360.0      50.0   75.00  86.13| 75.0  75.0  75.0  87.5  87.5  87.5
100.0|  0.0   0.0  50.0  50.0 100.0 100.0 100.0
WR2b            This water right has zero permitted diversion.
WR3a       240.0       0.0  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0
100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
WR3b            This water right has zero permitted diversion.
------------------------------------------------------------------------------
-------------------------------------------
 Total    1440.0      50.0            96.53
-------------------------------------------
```

END-OF-PERIOD RESERVOIR STORAGE AS A PERCENTAGE OF CAPACITY

$$\text{Percentage} = 100\% * (S - C1) / (C2 - C1) \quad \text{where}$$
$$S = \text{end-of-month storage}$$
$$C1,C2 = \text{user defined bottom and top of storage zone}$$

```
--------------------------------------
YEAR  MONTH      AVG    Res A   Res B
--------------------------------------
  1     1      82.70   80.00   85.40
  1     2      73.30   80.00   66.60
  1     3      64.35   80.00   48.70
  1     4      60.02   83.44   36.60
  1     5      60.73   86.66   34.80
  1     6      61.40   89.70   33.10
  1     7      89.26   78.52  100.00
  1     8      83.98   67.96  100.00
  1     9      78.97   57.94  100.00
  1    10      84.90   69.80  100.00
  1    11      90.00   80.00  100.00
  1    12      90.00   80.00  100.00
  2     1      82.70   80.00   85.40
  2     2      73.30   80.00   66.60
  2     3      64.35   80.00   48.70
  2     4      49.52   62.44   36.60
  2     5      40.27   45.74   34.80
  2     6      31.47   29.84   33.10
  2     7      76.62   53.24  100.00
  2     8      87.52   75.04  100.00
  2     9      97.69   95.38  100.00
  2    10      90.00   80.00  100.00
  2    11      90.00   80.00  100.00
```

```
    2    12     90.00   80.00  100.00
-------------------------------------
```


RESERVOIR STORAGE DRAWDOWN-DURATION SUMMARY

```
  number of years   =    2           Percentage = 100 - 100 * (S - C1) / (C2 - C1)
where
  periods per year  =   12                    S = end-of-month storage
  number of periods =   24             C1,C2 = user defined bottom and top of
storage zone


--------------------------------------------------------------------------------
-------------------------------------
            MEAN          BOTTOM      TOP          NUMBER OF PERIODS WITH
DRAWDOWNS EQUALING OR EXCEEDING PERCENT
NAME          STORAGE      OF ZONE    OF ZONE                              OF ZONE
STORAGE CAPACITY
            (AC-FT)       (AC-FT)    (AC-FT)       0%     2%     5%    10%
25%     50%    75%    90%    100%
--------------------------------------------------------------------------------
-------------------------------------
 Res A        369.94         0.       500.        24     24     23     23
7      2       0      0       0
 Res B         75.43         0.       100.        24     12     12     12
10      8       0      0       0
--------------------------------------------------------------------------------
-------------------------------------
```

Example 6

The *WRAP-SIM* input data for Example 6 are stored in one file named exam6.DAT which is reproduced later. *TABLES* input and output files (filenames tab6.DAT and tab6.OUT) are also shown. As indicated by the schematic below, the system configuration includes five control points located in one river basin and another control point located in another river basin. There are eleven water rights and four reservoirs. Very simple numbers are used in this example to facilitate manual tracking of the simulation computations.
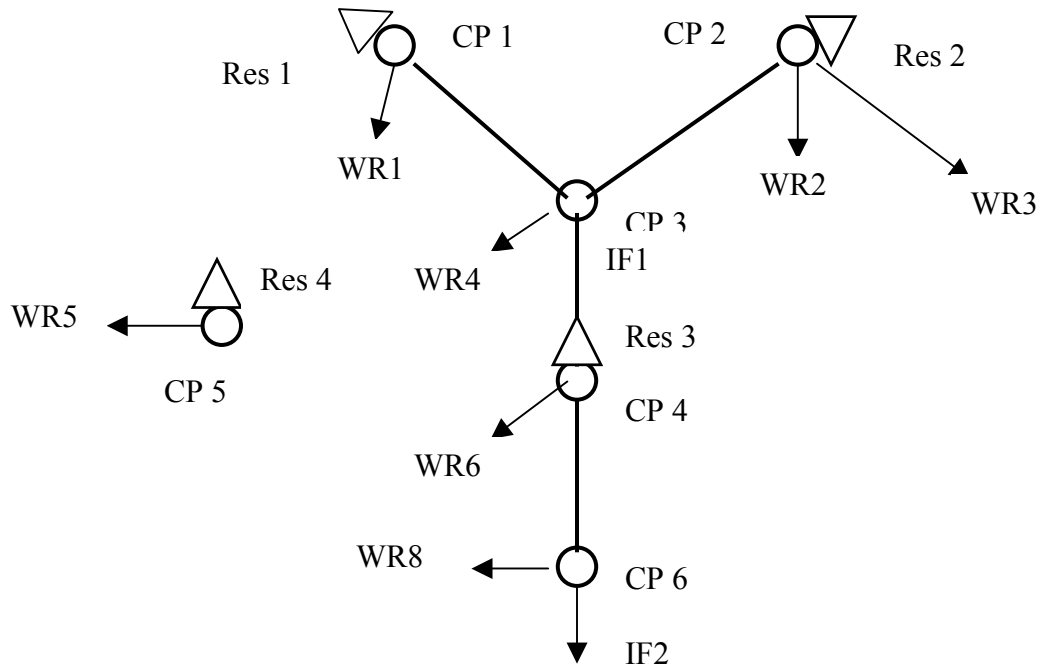
System Schematic for Example 6

Hydrology for Example 6

A 1997-1998 hydrologic period-of-analysis is used. Naturalized streamflows are provided on *IN* records for each month of the two-year simulation at each of the six control points. The naturalized flows are in acre-feet/month at all of the control points except CP5, which are in units of thousand cubic meters per month. A conversion factor of 0.811 ac-ft/1,000 m^3 is provided on the *CP* record for CP5.

Reservoir net evaporation-precipitation rates are entered on *EV* records for control points CP1 and CP2. The data for CP1 are also used at CP4 and CP5 (*CP* record field 9). The rates are in units of feet/month for CP1 and inches/month at CP2. The *CP* record for CP2 includes a conversion of 0.0833 foot/inch. The *NONE* on the CP records for CP3 and CP6 indicate that no evaporation-precipitation data are provided or required.

Example 6 Water Rights Listed in Priority Order

Water Right ID	Water Right Type	Control Point ID	Return Flow Location	Diversion Target (ac-ft/yr)	Instream Flow (ac-ft/yr)	Primary Reservoir Identifier	Primary Reservoir Capacity (ac-ft)	Secondary Reservoir Identifier
IF2	1	CP6			240			
IF1	1	CP3			120			
WR1	1	CP1	CP3	360		Res1	200	
WR2	1	CP2	CP3	60		Res2	50	
WR4	2	CP3		720				Res1
								Res2
								Res3
WR6	1	CP4		120				Res3
WR5a	2	CP5		600				Res3
								Res4
WR5b	1	CP5				Res4	200	
WR3	1	CP2	CP3	180		Res2	250	
WR8	4	CP6	CP3	varies				Res1
								Res2
								Res3
WR7	5	CP4		*		Res3	300	

* Permitted annual energy target for WR7 is 12,000 kilowatt-hours.

Example 6 Reservoir Storage Capacity

Reservoir Identifier	Primary or Secondary (P or S)	Water Right Identifier	Storage Capacity to Refill (ac-ft)	Inactive Pool Capacity (ac-ft)	Capacity at Top of Zone 1	Capacity at Top of Zone 2
Res1	P	WR1	200	10		
	S	WR4		10	200	200
	S	WR8		10	200	200
Res2	P	WR2	50	25		
	P	WR3	110	25		
	S	WR4		25	250	150
	S	WR8		25	250	125
Res3	P	WR6		30		
	P	WR9	300	30		
	S	WR4		30	300	165
	S	WR5b		150	300	300
	S	WR8		30	300	165
Res4	S	WR5a			200	100
	P	WR5b	200			

Volume versus Area Relationships for the Example 6 Reservoirs

A storage volume versus water surface area relationship is required for each of the four reservoirs for use in the evaporation computations. A table of storage volume, in acre-feet, versus area, in acres, is provided on _SV_ and _SA_ records for reservoir Res4.

The storage-volume relationships for the other three reservoirs are provided by the alternative option of entering the coefficients for Equation 7-1 in fields 4, 5, and 6 of the _WS_ record. With values of 0.1, 1.0, and 0.0 for coefficients _a_, _b_, and _c,_ respectively, for each of these reservoirs, Equation 7-1 reduces to:

area in acres = 0.1 (storage volume in acre-feet)

Water Rights for Example 6

Information associated with each water right is summarized in the tables on the next page. Diversion, instream flow, and hydropower requirements are provided in the first table. Reservoir storage capacities are tabulated in the second table.

Water Rights IF1 and IF2. - Water rights IF1 and IF2 are instream flow requirements at control points CP3 and CP4, respectively, of 120 ac-ft/year (10 ac-ft/month) and 240 ac-ft/year (20 ac-ft/month). With priority numbers of 191805 (May 1918) and 191803 (March 1918), these are the two most senior rights in the system.

Water Right WR1. - Water right WR1 located at control point CP1 has a permitted diversion of 360 ac-ft/yr, priority number of 192602 representing February 1926, and same-month return flow of 20% reentering the river at CP3. The annual diversion amount is converted to monthly diversions using the default constant monthly use factors. WR1 is a type 1 right with RES1 being its primary and only reservoir. Reservoir Res1 can be filled to a capacity of 200 ac-ft and supply water for the WR1 diversion until the storage level drops below the inactive pool capacity of 10 ac-ft. The volume-area relationship coefficients must be entered with WR1 since this is the first time Res1 is cited but do not have to be repeated on subsequent Res1 _WS_ records.

Water Rights WR2 and WR3. - Res2 is the primary (and only) reservoir for both WR2 and WR3, which can refill it to total cumulative capacities of 50 and 250 ac-ft, respectively. WR2 and WR3 have permitted annual diversion amounts of 60 and 180 ac-ft/yr, respectively, which are met by CP2 inflows as long as yet unappropriated streamflow is available and then withdrawals from Res2 as long as the storage is above the inactive pool capacity of 25 ac-ft. WR3 is junior to WR2. Several other rights at other locations have priorities which fall between WR2 and WR3.

Water Right WR4. - WR4 is a type 3 right with two secondary reservoirs but no primary reservoir. The WR4 diversion target is 720 ac-ft/yr or 60 ac-ft/month at CP3. Return flows of 40% the diversion amount renter the river at the default next downstream control point.

The WR4 diversion target is met first by available streamflow at CP3 and then, as necessary, by releases from reservoirs Res1 and Res2. WR4 is denoted a type 2 right since (unlike a type 1 right) it does not refill reservoir storage and (like a type 1 but unlike a type 3

right) it makes releases from Res1 and Res2 only if sufficient streamflow is not available at CP3 for the diversion.

Multiple-reservoir system operations are based on balancing the storage, as a percent of zone capacity, in each reservoir. *WRAP-SIM* computes a ranking factor for each reservoir using Equation 4-2.

$$rank\ factor\ =\ (weighting\ factor) \left[\frac{storage\ content\ in\ zone}{storage\ capacity\ of\ zone} \right] \tag{4-2}$$

The release is made from the reservoir with the greatest value for the rank factor. The reservoir zones are defined by Figure 4-1. Zone 1 must be empty in all the reservoirs in the system in order for releases to be made from zone 2 of any of the reservoirs.

The weighting factors used in the above formula are entered for each reservoir on the *OR* records. Weighting factors of either 1.0 or zero are used for the two zones of all reservoirs in the example. Since only the relative magnitude between reservoirs matters, replacing the 1.0's with any positive constant number will yield the same result. Since the zeroes are assigned to zones with zero storage capacity, any other number will yield the same result.

For water right WR4, the Res2 cumulative storage capacities at the top of inactive zone, active zone 2, and active zone 1 are 25 ac-ft, 150 ac-ft, and 250 ac-ft. Thus, zones 1 and 2 have capacities of 100 ac-ft (250-150), and 125 ac-ft (150-25), respectively. Res1 has cumulative storage capacities at the top of inactive zone, active zone 2, and active zone 1 of 10, 90, and 90 ac-ft, respectively. Since *WS* record field 3 and *OR* record field 3 both contain values of 200 ac-ft, Res2 zone 1 contains zero storage capacity. In order for a release to be made from Res1, the storage contents of Res2 must be below 150 ac-ft.

Water Rights WR5a and WR5b. Since multiple-reservoir release decisions are pertinent only to secondary reservoirs and storage capacity can be replenished only in a primary reservoir, WR5 is treated as two separate water rights WR5a and WR5b. Water right WR5a has a diversion of 50 ac-ft/month (600 ac-ft/yr.) located at CP5 which is met by available streamflow at CP5 supplemented by releases from reservoirs Res3 and Res4. WR5b refills storage in Res4 from available streamflow. WR5b is assigned a priority junior to WR5a so that the Res4 storage capacity is refilled after, rather than before, the WR5a diversion and associated release decisions are completed.

With the exception of Res4, the reservoirs are full at the beginning of the simulation on 1 January 1997. The storage content of Res4 is 100 ac-ft when the simulation begins.

The WR5a diversion is supplied by water from the following sources in the order listed:

(1) streamflows at CP5 (inflows to Res4) until the streamflow is depleted

(2) releases or withdrawals from Res4 until the reservoir is emptied to less than half of its storage capacity

(3) releases and withdrawals from both Res3 and Res4 until Res3 is emptied to less than half of its storage capacity and Res4 is empty

When both Res3 and Res4 are supplying water, release decisions are based on balancing the percent full (or percent depleted) of specified zones consisting of the lower half of Res4 and the upper half of Res3. Shortages occur if the indicated streamflow and reservoir storage is insufficient to meet the permitted diversion. This WR5a multiple-reservoir operating policy is defined in the *WRAP-SIM* input file as follows. Active pool zone 1 (Figure 4-1) in Res4 has a capacity of 100 ac-ft since the total cumulative capacities at the top of zone 1 is 200 ac-ft and at the top of zone 2 (bottom of zone 1) is 100 ac-ft. The inactive pool has zero storage. Thus, the Res4 storage capacity is divided in half, with 100 ac-ft in the upper zone 1 and 100 ac-ft in the lower zone 2. For WR5a, reservoir Res3 has cumulative capacities at the top of inactive pool, active pool zone 2, and zone 1 of 150 ac-ft, 300 ac-ft, and 300 ac-ft. Thus, zone 1 in Res3 has zero capacity. Res4 must be half empty before water is taken from Res3. Likewise, water is not withdrawn from Res3 for WR5 if the storage content of Res3 falls below 150 ac-ft.

CP5 is located in a different river basin than the other control points. Water withdrawn from Res3 and CP4 is conveyed by pipeline (or some means other than the gravity flow in river channels) to the WR5a diversion site at CP5. Consequently, a negative one is entered in field 6 of the *OR* record. A negative integer in this field has the effect of acting as a switch to allow a reservoir to release to a diversion with a control point location which is not downstream of the reservoir. Field 11 of the *WS* record is also flagged with a negative integer indicating that the WR5a releases from Res3 do not pass through the hydroelectric power plant associated with water right WR7.

Water Right WR6. - WR6 diverts 120 ac-ft/yr at CP4 from available streamflow and Res4 storage. Since WR6 is not permitted to refill storage, a type 2 right is specified.

Water Right WR7. - WR7 generates hydroelectric power and refills storage in Res3. With a POWFCT value of 1.0237, the energy units are kilowatt-hours. The permitted firm energy is a constant 12,000 kW-hr. The cumulative total storage capacity and inactive pool (bottom of power pool) capacity are 300 ac-ft and 30 ac-ft respectively. The tailwater elevation is 5.0 feet, and the plant efficiency is 85%. All flows through control point CP4 can be diverted through the hydroelectric turbines except for the lakeside withdrawals from Res3 for WR5. WR7 is a type 5 right with Res3 as the primary (and only) reservoir.

Res3 storage versus elevation data, used to compute the head term of the power equation, are provided on *PV* and *PE* records. The elevation is assumed to vary linearly from zero to 100 feet as storage varies from zero to 300 ac-ft.

Water Right WR8. - WR8 is a type 3 diversion right with the permitted diversion amount being supplied only by reservoirs Res1, Res2, and Res3 without appropriating streamflows at CP6. The diversion target is a function of month of the year (*WR* record field 4 and *UC* records). The permitted diversion is zero during the months from September through April (*UC* records). During the remaining four months, the permitted diversion is ac-ft/month.

WRAP-SIM Input File for Example 6

```
T1  WRAP-SIM Input File Exam6.DAT
T2  Example 6 from Appendix G of Reference Manual
**
**                 Fixed-Width Fields and Columns
**   2 !     3 !     4 !     5 !     6 !     7 !     8 !     9 !    10 !    11 !
12 !
** 3-8 !  9-16 ! 17-24 ! 25-32 ! 33-40 ! 41-48 ! 49-56 ! 57-64 ! 65-72 ! 73-80 !
81-88 !
**
FO   -1      -1      -1
JD    2    1997       1      -1      -1       0       0       0       0       0
1.0237
RO    1    RES3
**
**  Monthly Use Factors
**
UC   MUN   0.06    0.06    0.07    0.07    0.08    0.10
UC         0.13    0.12    0.09    0.08    0.08    0.06
UC IRRIG      0       0       0       0    0.25    0.25
UC         0.25    0.25       0       0       0       0
**
**  Control Point Records
**
CP   CP1     CP3
CP   CP2     CP3         0.08333
CP   CP3     CP4                                      NONE
CP   CP4     CP6                                       CP1
CP   CP5     OUT   0.811                               CP1
CP   CP6     OUT                                      NONE
**
**  Water Rights and Associated Reservoirs
**
**  Water Right IF2  ----------------------------------------------------
IF   CP6    240          191803                        IF2
**  Water Right IF1  ----------------------------------------------------
IF   CP3    120          191805                        IF1
**  Water Right WR1  ----------------------------------------------------
WR   CP1    360.         192602  1          .2                          WR1
WS   RES1   200.      .1      1.      0.     10.
**  Water Right WR2  ----------------------------------------------------
WR   CP2     60.   IRRIG 193908  1          .2                          WR2
WS   RES2    50.      .1      1.      0.     25.
**  Water Right WR3  ----------------------------------------------------
WR   CP2    180.         196506  1          .2              WR3
WS   RES2   250.      .1      1.      0.     25.
**  Water Right WR4  ----------------------------------------------------
WR   CP3    720.    MUN  195207  2         0.4              WR4
WS   RES2   250.                           25.
OR         125.       1       1
WS   RES1   200.                           10.
OR         200.       0       1
**  Water Rights WR5a and WR5b  -----------------------------------------
WR   CP5      0.         196213  1                          WR5b
WS   RES4   200.      -1                    100.
WR   CP5    600.         196212  2                          WR5a
WS   RES4   200.      -1
```

```
OR          100.        1        1       -1
WS  RES3    300.        .1       1.       0.     150.                                          -1
OR  CP4     300.        1        1
** Water Right WR6  -----------------------------------------------------
WR  CP4     120.              195704   2                                    WR6
WS  RES3    300.        .1       1.       0.      30.
** Water Right WR7  -----------------------------------------------------
WR  CP4   12000.              197801   5                                    WR9
WS  RES3    300.                                 30.               5.      .85
** Water Right WR8  -----------------------------------------------------
WR  CP6     400.    IRRIG 197412   3    2                                   WR8
WS  RES2    250.                                 25.
OR          125.        1        1
WS  RES1    200.                                 10.
OR          200.        0        1
WS  RES3    300.        .1       1.       0.      30.
OR          165.        1        1
**
** Storage versus Area Table for Reservoir RES4
**
SV  RES4      0.     200.
SA            0.      20.
**
** Storage versus Elevation Table for Reservoir RES3
**
PV  RES3      0.     300.
PE            0.     100.
**
ED
**
** Naturalized Streamflow and Net Evaporation-Precipitation Rates
**
IN  CP1    1997       60       60       60       60       60       60       10       10
10      10       10       10
IN  CP2    1997       20       20       20       20       20       20        0        0
0       0        0        0
IN  CP5    1997       74       74       74    12.33    12.33    12.33    12.33    12.33
12.33    92.5     92.5     92.5
IN  CP3    1997      120      120      120      100      100      100       30       30
30      30       30       30
IN  CP4    1997      120      120      120      120      120      120       40       40
40      40       40       40
IN  CP6    1997      150      150      150      180      180      180       50       50
50      50       50       50
EV  CP1    1997       .5       .5       .5       .5       .5       .5       .5       .5
.5      .5       .5       .5
EV  CP2    1997       6.       6.       6.       6.       6.       6.       6.       6.
6.      6.       6.       6.
IN  CP1    1998       60       60       60      300      300      300       10       10
10      10       10       10
IN  CP2    1998       20       20       20      100      100      100        0        0
0       0        0        0
IN  CP5    1998       74       74       74    61.67    61.67    61.67    12.33    12.33
12.33    92.5     92.5     92.5
IN  CP3    1998      120      120      120      500      500      500       30       30
30      30       30       30
IN  CP4    1998      120      120      120      600      600      600       40       40
40      40       40       40
```

Appendix G - WRAP-SIM Examples   194

```
IN    CP6    1998      150       150       150       900       900       900       50        50
50       50        50        50
EV    CP1    1998      .5        .5        .5        .5        .5        .5        .5        .5
.5       .5        .5        .5
EV    CP2    1998      6.        6.        6.        6.        6.        6.        6.        6.
6.       6.        6.        6.
```

TABLES Input File for Example 6

```
COMM    TABLES Input File Tab6.DAT
COMM    Example 6
2REL
2REL        2    1      RES3
2FRE    1
2FRE    2
2FRE    3
2FRE    4    4      CP1       CP2       CP4       CP5
2REG    1    1    1
2UNA    1    1    0
ENDF
```

TABLES Output File for Example 6

RELIABILITY SUMMARY FOR SELECTED CONTROL POINTS

```
------------------------------------------------------------------------------------
----------------------------------------
         TARGET      MEAN    *RELIABILITY*| +++++++++ PERCENTAGE OF MONTHS +++++++++|-
--------- PERCENTAGE OF YEARS ----------
NAME     DIVERSION  SHORTAGE  PERIOD VOLUME|   WITH DIVERSIONS EQUALING OR EXCEEDING
PERCENTAGE OF TARGET DIVERSION AMOUNT
         (AC-FT/YR) (AC-FT/YR)  (%)    (%) | 100%   95%   90%   75%   50%   25%  >0% |
100%  98%   95%   90%   75%   50%   >0%
------------------------------------------------------------------------------------
----------------------------------------
   CP1      360.0      82.0   66.67  77.22| 66.7  66.7  66.7  66.7  66.7 100.0 100.0|
 0.0   0.0   0.0   0.0 100.0 100.0 100.0
   CP2      240.0      67.8   58.33  71.73| 58.3  62.5  62.5  62.5  66.7  66.7 100.0|
 0.0   0.0   0.0   0.0   0.0 100.0 100.0
   CP3      720.0     165.5   62.50  77.01| 62.5  66.7  66.7  66.7  70.8  79.2 100.0|
 0.0   0.0   0.0   0.0  50.0 100.0 100.0
   CP4      120.0       0.0  100.00 100.00|100.0 100.0 100.0 100.0 100.0 100.0
100.0|100.0 100.0 100.0 100.0 100.0 100.0 100.0
   CP5      600.0      29.0   91.67  95.17| 91.7  91.7  91.7  91.7  95.8  95.8 100.0|
50.0  50.0  50.0 100.0 100.0 100.0 100.0
   CP6      400.0       8.0   87.50  98.00| 87.5  87.5  87.5 100.0 100.0 100.0 100.0|
50.0  50.0 100.0 100.0 100.0 100.0 100.0
------------------------------------------------------------------------------------
----------------------------------------
 Total    2440.0     352.4          85.56
--------------------------------------------
```

RELIABILITY SUMMARY FOR SELECTED HYDROELECTRIC POWER PROJECTS

```
------------------------------------------------------------------------------------
----------------------------------------
         ENERGY     MEAN    *RELIABILITY*  +++++++++ PERCENTAGE OF MONTHS +++++++++|-
--------- PERCENTAGE OF YEARS ----------
NAME     TARGET    SHORTAGE   PERIOD AMOUNT        WITH ENERGY GENERATION EQUALING
OR EXCEEDING PERCENTAGE  OF TARGET
                              (%)    (%)   100%   95%   90%   75%   50%   25%  >0% |
100%  98%   95%   90%   75%   50%   >0%
------------------------------------------------------------------------------------
----------------------------------------
  RES3   12000.0    3093.6   70.83  74.22| 70.8  70.8  70.8  70.8  70.8  75.0 100.0|
 0.0   0.0   0.0   0.0  50.0 100.0 100.0
------------------------------------------------------------------------------------
----------------------------------------
 Total   12000.0    3093.6          74.22
--------------------------------------------
```

FLOW-FREQUENCY FOR NATURALIZED STREAMFLOWS

```
------------------------------------------------------------------------------------
--------------------------------
```

```
CONTROL         STANDARD     PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING
VALUES SHOWN IN THE TABLE
 POINT    MEAN DEVIATION 100%     99%     98%     95%     90%     75%     60%     50%
40%    25%    10%  MAXIMUM
-----------------------------------------------------------------------------------
   CP1      65.0    93.8   10.0    10.0    10.0    10.0    10.0    10.0    10.     60.
60.    60.   300.    300.
   CP2      20.0    32.3    0.0     0.0     0.0     0.0     0.0     0.0     0.     20.
20.    20.   100.    100.
   CP3     120.0   152.0   30.0    30.0    30.0    30.0    30.0    30.0    30.    100.
108.   120.   500.    500.
   CP4     140.0   181.6   40.0    40.0    40.0    40.0    40.0    40.0    40.    120.
120.   120.   600.    600.
   CP5      43.8    27.8   10.0    10.0    10.0    10.0    10.0    10.0    50.     60.
60.    75.    75.     75.
   CP6     197.5   276.3   50.0    50.0    50.0    50.0    50.0    50.0    50.    150.
150.   180.   900.    900.
-----------------------------------------------------------------------------------
```

FLOW-FREQUENCY FOR REGULATED STREAMFLOWS

```
-----------------------------------------------------------------------------------
CONTROL         STANDARD     PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING
VALUES SHOWN IN THE TABLE
 POINT    MEAN DEVIATION 100%     99%     98%     95%     90%     75%     60%     50%
40%    25%    10%  MAXIMUM
-----------------------------------------------------------------------------------
   CP1      45.1    73.6    0.0     0.0     0.0     0.0     0.0     0.0    12.     20.
22.    65.   207.    260.
   CP2      10.1    20.5    0.0     0.0     0.0     0.0     0.0     0.0     0.      0.
0.    14.    58.     67.
   CP3      51.5    87.6   10.0    10.0    10.0    10.0    10.0    10.0    13.     13.
21.    30.   255.    314.
   CP4      59.4   114.7    0.0     0.0     0.0     0.0     0.0     0.0     0.      2.
10.   100.   282.    408.
   CP5       0.0     0.0    0.0     0.0     0.0     0.0     0.0     0.0     0.      0.
0.     0.     0.      0.
   CP6      97.1   168.3   10.0    10.0    10.0    10.0    10.0    23.3    37.     48.
49.    60.   492.    608.
-----------------------------------------------------------------------------------
```

FLOW-FREQUENCY FOR UNAPPROPRIATED STREAMFLOWS

```
--------------------------------------------------------------------------------
---------------------------------
CONTROL          STANDARD    PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING
VALUES SHOWN IN THE TABLE
 POINT      MEAN DEVIATION  100%     99%      98%      95%      90%      75%      60%      50%
40%     25%     10%  MAXIMUM
--------------------------------------------------------------------------------
---------------------------------
   CP1      22.4    73.2     0.0      0.0      0.0      0.0      0.0      0.0      0.       0.
0.       2.    158.    260.
   CP2       0.1     0.6     0.0      0.0      0.0      0.0      0.0      0.0      0.       0.
0.       0.      0.      3.
   CP3      25.5    83.7     0.0      0.0      0.0      0.0      0.0      0.0      0.       0.
0.       2.    176.    304.
   CP4      26.7    86.1     0.0      0.0      0.0      0.0      0.0      0.0      0.       0.
0.       2.    189.    308.
   CP5       0.0     0.0     0.0      0.0      0.0      0.0      0.0      0.0      0.       0.
0.       0.      0.      0.
   CP6      78.8   167.4     0.0      0.0      0.0      0.0      0.0      3.3     17.      28.
29.     40.    472.    588.
--------------------------------------------------------------------------------
---------------------------------
```

STORAGE-FREQUENCY FOR SPECIFIED CONTROL POINTS

```
--------------------------------------------------------------------------------
---------------------------------
CONTROL          STANDARD    PERCENTAGE OF MONTHS WITH STORAGE EQUALING OR EXCEEDING
VALUES SHOWN IN THE TABLE
 POINT      MEAN DEVIATION  100%     99%      98%      95%      90%      75%      60%      50%
40%     25%     10%  MAXIMUM
--------------------------------------------------------------------------------
---------------------------------
   CP1       89.     86.    10.      10.      10.      10.      10.      10.      23.      55.
121.    200.    200.    200.
   CP2       96.     87.    21.      21.      21.      22.      22.      24.      27.      53.
97.    179.    236.    243.
   CP4      164.    110.    30.      30.      30.      30.      30.      30.     136.     178.
213.    300.    300.    300.
   CP5       62.     33.     0.       0.       0.       5.      23.      30.      68.      72.
76.     84.    108.    114.
--------------------------------------------------------------------------------
---------------------------------
```

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP1

```
--------------------------------------------------------------------------------
----------------------------------------
YEAR       JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP
OCT       NOV      DEC    TOTAL
--------------------------------------------------------------------------------
----------------------------------------
1997       20.      20.      20.      20.      36.      51.      75.      24.       0.
0.       0.       0.    265.
```

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
OCT	NOV	DEC	TOTAL						
1998	7.	7.	14.	129.	260.	260.	75.	65.	0.
0.	0.	0.	817.						
MEAN	14.	14.	17.	74.	148.	155.	75.	45.	0.
0.	0.	0.	541.						

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
OCT	NOV	DEC	TOTAL						
1997	0.	0.	0.	14.	19.	67.	0.	11.	0.
0.	0.	0.	112.						
1998	0.	0.	0.	0.	0.	0.	17.	62.	52.
0.	0.	0.	131.						
MEAN	0.	0.	0.	7.	10.	34.	8.	37.	26.
0.	0.	0.	122.						

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP3

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
OCT	NOV	DEC	TOTAL						
1997	26.	26.	19.	13.	30.	78.	13.	10.	10.
10.	10.	10.	253.						
1998	13.	13.	13.	187.	314.	300.	30.	73.	10.
10.	10.	10.	983.						
MEAN	19.	19.	16.	100.	172.	189.	21.	42.	10.
10.	10.	10.	618.						

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP4

```
----------------------------------------------------------------------------------
--------------------------------------
YEAR        JAN       FEB       MAR      APR      MAY      JUN      JUL      AUG      SEP
OCT       NOV       DEC       TOTAL
----------------------------------------------------------------------------------
--------------------------------------
1997         6.        6.        2.      16.     100.     100.     100.      84.       0.
0.        0.        0.       414.
1998         0.        0.        0.       0.     408.     404.     100.     100.       0.
0.        0.        0.      1012.
MEAN         3.        3.        1.       8.     254.     252.     100.      92.       0.
0.        0.        0.       713.
----------------------------------------------------------------------------------
--------------------------------------
```

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP5

```
----------------------------------------------------------------------------------
--------------------------------------
YEAR        JAN       FEB       MAR      APR      MAY      JUN      JUL      AUG      SEP
OCT       NOV       DEC       TOTAL
----------------------------------------------------------------------------------
--------------------------------------
1997         0.        0.        0.       0.       0.       0.       0.       0.       0.
0.        0.        0.        0.
1998         0.        0.        0.       0.       0.       0.       0.       0.       0.
0.        0.        0.        0.
MEAN         0.        0.        0.       0.       0.       0.       0.       0.       0.
0.        0.        0.        0.
----------------------------------------------------------------------------------
--------------------------------------
```

REGULATED STREAMFLOWS (AC-FT) AT CONTROL POINT CP6

```
----------------------------------------------------------------------------------
--------------------------------------
YEAR        JAN       FEB       MAR      APR      MAY      JUN      JUL      AUG      SEP
OCT       NOV       DEC       TOTAL
----------------------------------------------------------------------------------
--------------------------------------
1997        48.       48.       44.      88.      60.      60.      10.      10.      53.
23.       23.       23.       491.
1998        49.       49.       52.     323.     608.     604.      10.      10.      29.
32.       35.       39.      1840.
MEAN        48.       48.       48.     206.     334.     332.      10.      10.      41.
28.       29.       31.      1166.
----------------------------------------------------------------------------------
--------------------------------------
```

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP1

```
----------------------------------------------------------------------------------
--------------------------------------
```

```
YEAR        JAN       FEB       MAR    APR      MAY      JUN      JUL      AUG      SEP
OCT    NOV       DEC       TOTAL
-------------------------------------------------------------------------------------
---------------------------------------
1997         6.        6.        2.     3.       0.       0.       0.       0.       0.
0.     0.        0.        17.
1998         0.        0.        0.     0.     260.     260.       0.       0.       0.
0.     0.        0.        520.
MEAN         3.        3.        1.     2.     130.     130.       0.       0.       0.
0.     0.        0.        268.
-------------------------------------------------------------------------------------
---------------------------------------
```

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP2

```
-------------------------------------------------------------------------------------
---------------------------------------
YEAR        JAN       FEB       MAR    APR      MAY      JUN      JUL      AUG      SEP
OCT    NOV       DEC       TOTAL
-------------------------------------------------------------------------------------
---------------------------------------
1997         0.        0.        0.     3.       0.       0.       0.       0.       0.
0.     0.        0.        3.
1998         0.        0.        0.     0.       0.       0.       0.       0.       0.
0.     0.        0.        0.
MEAN         0.        0.        0.     2.       0.       0.       0.       0.       0.
0.     0.        0.        2.
-------------------------------------------------------------------------------------
---------------------------------------
```

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP3

```
-------------------------------------------------------------------------------------
---------------------------------------
YEAR        JAN       FEB       MAR    APR      MAY      JUN      JUL      AUG      SEP
OCT    NOV       DEC       TOTAL
-------------------------------------------------------------------------------------
---------------------------------------
1997         6.        6.        2.     3.       0.       0.       0.       0.       0.
0.     0.        0.        17.
1998         0.        0.        0.     0.     304.     290.       0.       0.       0.
0.     0.        0.        594.
MEAN         3.        3.        1.     2.     152.     145.       0.       0.       0.
0.     0.        0.        306.
-------------------------------------------------------------------------------------
---------------------------------------
```

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP4

```
------------------------------------------------------------------------------------
------------------------------------------
YEAR       JAN       FEB       MAR      APR      MAY      JUN      JUL      AUG      SEP
OCT       NOV       DEC      TOTAL
------------------------------------------------------------------------------------
------------------------------------------
1997        6.        6.        2.      16.       0.       0.       0.       0.       0.
0.        0.        0.       30.
1998        0.        0.        0.       0.     308.     304.       0.       0.       0.
0.        0.        0.      612.
MEAN        3.        3.        1.       8.     154.     152.       0.       0.       0.
0.        0.        0.      321.
------------------------------------------------------------------------------------
------------------------------------------
```

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP5

```
------------------------------------------------------------------------------------
------------------------------------------
YEAR       JAN       FEB       MAR      APR      MAY      JUN      JUL      AUG      SEP
OCT       NOV       DEC      TOTAL
------------------------------------------------------------------------------------
------------------------------------------
1997        0.        0.        0.       0.       0.       0.       0.       0.       0.
0.        0.        0.        0.
1998        0.        0.        0.       0.       0.       0.       0.       0.       0.
0.        0.        0.        0.
MEAN        0.        0.        0.       0.       0.       0.       0.       0.       0.
0.        0.        0.        0.
------------------------------------------------------------------------------------
------------------------------------------
```

UNAPPROPRIATED FLOWS (AC-FT) AT CONTROL POINT CP6

```
------------------------------------------------------------------------------------
------------------------------------------
YEAR       JAN       FEB       MAR      APR      MAY      JUN      JUL      AUG      SEP
OCT       NOV       DEC      TOTAL
------------------------------------------------------------------------------------
------------------------------------------
1997       28.       28.       24.      68.      40.      40.       0.       0.      33.
3.        3.        3.      271.
1998       29.       29.       32.     303.     588.     584.       0.       0.       9.
12.       15.       19.     1620.
MEAN       28.       28.       28.     186.     314.     312.       0.       0.      21.
8.        9.       11.      946.
------------------------------------------------------------------------------------
------------------------------------------
```

```
             REG       REG       REG      REG      REG      REG      UNA      UNA
UNA       UNA       UNA       UNA
```

Year	Month	CP1	CP2	CP3	CP4	CP5	CP6	CP1	CP2	CP3	CP4	CP5	CP6
1997	1	20.0	0.0	25.8	6.0	0.0	48.1	6.0	0.0	6.0	6.0	0.0	28.1
1997	2	20.0	0.0	25.8	6.0	0.0	48.1	6.0	0.0	6.0	6.0	0.0	28.1
1997	3	20.0	0.0	18.6	1.7	0.0	43.8	1.7	0.0	1.7	1.7	0.0	23.8
1997	4	20.0	14.4	13.0	16.1	0.0	88.2	3.0	3.0	3.0	16.1	0.0	68.2
1997	5	36.1	19.1	29.6	100.0	0.0	60.0	0.0	0.0	0.0	0.0	0.0	40.0
1997	6	50.5	67.0	77.5	100.0	0.0	60.0	0.0	0.0	0.0	0.0	0.0	40.0
1997	7	74.6	0.0	13.0	100.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0
1997	8	23.8	11.3	10.0	84.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0
1997	9	0.0	0.0	10.0	0.0	0.0	53.4	0.0	0.0	0.0	0.0	0.0	33.4
1997	10	0.0	0.0	10.0	0.0	0.0	23.3	0.0	0.0	0.0	0.0	0.0	3.3
1997	11	0.0	0.0	10.0	0.0	0.0	23.3	0.0	0.0	0.0	0.0	0.0	3.3
1997	12	0.0	0.0	10.0	0.0	0.0	23.3	0.0	0.0	0.0	0.0	0.0	3.3
1998	1	7.2	0.0	12.9	0.0	0.0	48.6	0.0	0.0	0.0	0.0	0.0	28.6
1998	2	7.2	0.0	13.0	0.0	0.0	48.8	0.0	0.0	0.0	0.0	0.0	28.8
1998	3	14.4	0.0	13.0	0.0	0.0	51.7	0.0	0.0	0.0	0.0	0.0	31.7
1998	4	128.5	0.0	187.1	0.0	0.0	323.3	0.0	0.0	0.0	0.0	0.0	303.3
1998	5	260.0	0.0	314.4	408.3	0.0	608.3	260.0	0.0	304.4	308.3	0.0	588.3
1998	6	260.0	0.0	300.0	403.8	0.0	603.8	260.0	0.0	290.0	303.8	0.0	583.8
1998	7	74.6	16.6	29.6	100.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0
1998	8	65.3	62.4	73.3	100.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0
1998	9	0.0	52.4	10.0	0.0	0.0	29.2	0.0	0.0	0.0	0.0	0.0	9.2
1998	10	0.0	0.0	10.0	0.0	0.0	32.2	0.0	0.0	0.0	0.0	0.0	12.2
1998	11	0.0	0.0	10.0	0.0	0.0	34.9	0.0	0.0	0.0	0.0	0.0	14.9
1998	12	0.0	0.0	10.0	0.0	0.0	39.0	0.0	0.0	0.0	0.0	0.0	19.0

Example 7

The purpose of Example 7 is to illustrate the use of target options *SO* and target series *TS* records in specifying instream flow and diversion targets. The *TABLES* output file is developed in a columnar format that facilitates transporting the simulation results to a spreadsheet program for plotting or other data manipulations. A schematic of the system is provided below and each water right is described.
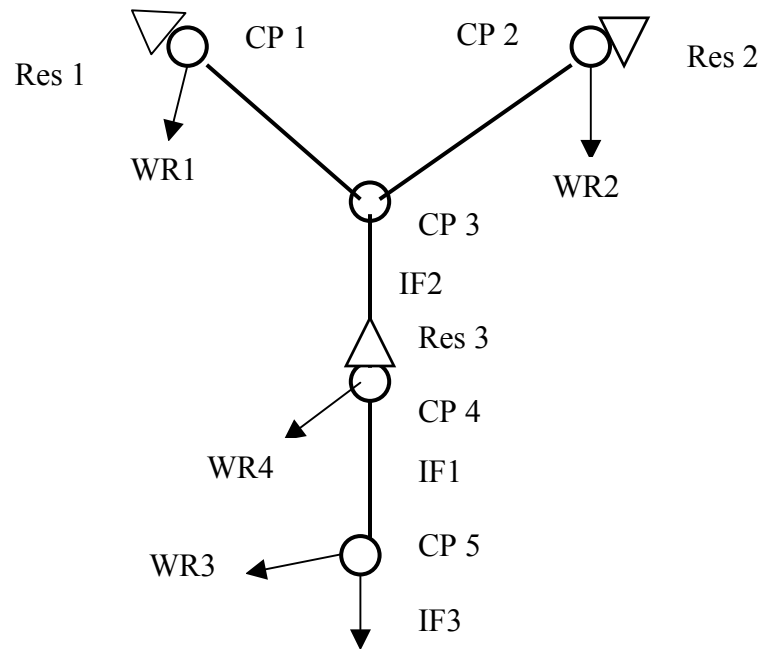
System Schematic for Example 7

Instream Flow Right IF 1. The instream flow target at control point CP4 is set equal to the incremental naturalized flows entering the river above CP4 and below CP1 and CP2 constrained by lower and upper bounds. *TO* records are used to subtract (*NFACT*= -1) the naturalized (*TOFLOW*=1) flows at CP1 and CP2 from those at CP4. Instream flow right *IF1* has another feature that limits the target to the range from 3 to 68 ac-ft/month (*TO* record fields 7 and 8). If the incremental (CP4 - CP1 - CP2) flow is below 3 ac-ft, the target is set at 3 ac-ft. Likewise, if the CP4-CP1-CP2 naturalized flow is above 68 ac-ft, the target is set at 68 ac-ft.

Instream Flow Right IF 2. An instream flow requirement at CP3 varies between the two years of the simulation period-of-analysis. A *TS* record is entered for each year.

Instream Flow Right IF 3. The instream flow target at CP5 consists of the flow values entered on the *TS* record added to the minimum of: (a) 100 ac-ft/month or (b) the naturalized streamflow at CP5.

Water Rights WR 1, WR 2, and WR 4. These are standard type 1 rights with both a diversion and reservoir storage.

Water Right WR 3. *WR3* is a run-of-river diversion right at control point CP5. The monthly diversion target is the lesser of 300 ac-ft or the naturalized streamflow at CP5.

Water Rights WR 5 and WR 7. *WR5* diverts water from reservoir *Res 3* at CP4 and transports it to CP1 for refilling by *WR7* of storage in *Res 1*. The *WR5* diversion target is computed as the minimum of the drawdown in *Res 1* and the regulated flow at CP1. This models a situation is which *Res 1* and *Res 3* are operated as a system with the operating rules being based on maintaining as much storage in *Res 1* as possible even though *Res 3* has the more senior water right permit. There is actually no pipeline/pumping facility. Flows are allocated in accordance with the water rights priority system except *WR5* and *WR7* are added at the end of the priority loop to reallocate releases from *Res 1* back to *Res 1* from *Res 3*. Thus, the *WR5 dummy* diversion is limited to the regulated flows below *Res 1* (representing downstream releases) and the storage drawdown in *Res 1*. *WR7* uses the water diverted to CP1 to refill *Res 1*.

Water Rights WR 6 and WR 8. *WR6* diverts water from reservoir *Res 3* at CP4 and transports it to CP2 for refilling by *WR8* of storage in *Res 2*. This models a situation is which *Res 1* and *Res 3* are operated as a system with the operating rules being based on maintaining as much storage in *Res 1* as possible even though *Res 3* has the more senior water right permit. There is a pipeline/pumping facility so flows are not limited to the regulated flows below *Res 2* as done for *WR 5* above.

WRAP-SIM FLO File for Example 7

```
**   WRAP-SIM Input File Exam7.FLO
**   Example 7 from Appendix G of Reference Manual
**
**   Naturalized Streamflow
**
IN   CP1   1997     60      60      60     120     120     120      10      10
10      10      10      10
IN   CP2   1997     20      20      20      90      90      90       0       0
0       0       0       0
IN   CP3   1997    120     120     120     240     240     240      30      30
30      30      30      30
IN   CP4   1997    120     120     120     460     460     460      40      40
40      40      40      40
IN   CP5   1997    150     150     150     680     680     680      50      50
50      50      50      50
IN   CP1   1998     60      60      60     300     300     300      10      10
10      10      10      10
IN   CP2   1998     20      20      20     100     100     100       0       0
0       0       0       0
IN   CP3   1998    120     120     120     500     500     500      30      30
30      30      30      30
IN   CP4   1998    120     120     120     600     600     600      40      40
40      40      40      40
IN   CP5   1998    150     150     150     900     900     900      50      50
50      50      50      50
```

WRAP-SIM DAT File for Example 7

```
T1  WRAP-SIM Input File Exam7.DAT
T2  Example 7 from Appendix G of Reference Manual
**
FO            -1       -1
JD    2   1997        1      -1      -1
RO    3   Res 1   Res 2   Res 3
**
CP   CP1     CP3                                      NONE
CP   CP2     CP3                                      NONE
CP   CP3     CP4                                      NONE
CP   CP4     CP5                                      NONE
CP   CP5     OUT                                      NONE
**
**!  2 !    3 !     4 !     5 !     6 !     7 !     8 !     9 !    10 !    11
!   12 !   13 !    14 !
**! 3-8 !  9-16 ! 17-24 ! 25-32 ! 33-40 ! 41-48 ! 49-56 ! 57-64 ! 65-72 ! 73-80
! 81-88 ! 89-96 ! 97-104!
**
**  Water Right IF1  -----------------------------------------------------------
------------------------
IF   CP4                       1900        2                     IF1
TO    1                                          CP4                        CONT
TO    1  - 1.0     ADD                           CP1                        CONT
TO    1  - 1.0     ADD    3.0    68.0    CP2
**  Water Right IF2  -----------------------------------------------------------
------------------------
IF   CP3                       1901        2                     IF2
TS         1997    20.     20.     20.     20.     20.     20.     20.     20.
20.     20.     20.     20.
TS         1998    15.     15.     15.     15.     15.     15.     15.     15.
15.     15.     15.     15.
**  Water Right IF3  -----------------------------------------------------------
------------------------
IF   CP5   1200.               1902        2                     IF3
TO    1            MIN                            CP5
TS   ADD19971998   25.     25.     25.     30.     30.     30.      0.      0.
0.     40.     40.     40.
**  Water Right WR1  -----------------------------------------------------------
------------------------
WR   CP1   2400.               1985                              WR1
WS Res 1   5000.       .1     1.
**  Water Right WR2  -----------------------------------------------------------
------------------------
WR   CP2   2400.               1978                              WR2
WS Res 2   5000.       .1     1.
**  Water Right WR3  -----------------------------------------------------------
------------------------
WR   CP5   4800.               1903                              WR3
TO    1            MIN                            CP5
**  Water Right WR4  -----------------------------------------------------------
------------------------
WR   CP4   3600.               1950                              WR4
WS Res 3   8000.       .1     1.
**  Water Right WR5  -----------------------------------------------------------
------------------------
WR   CP4      0.               2000   3         1.0     CP1     WR5
```

```
WS Res 3   8000.     .1      1.
TO    5                                              Res 1                        CONT
TO    2              MIN                    CP1
**  Water Right WR6  ----------------------------------------------------------------
------------------------
WR  CP4     0.           2000  3         1.0   CP2       WR6
WS Res 3   8000.     .1      1.
TO    5                                              Res 2
**  Water Right WR7  ----------------------------------------------------------------
------------------------
WR  CP1     0.           2001                                 WR7
WS Res 1   5000.     .1      1.
**  Water Right WR8  ----------------------------------------------------------------
------------------------
WR  CP2     0.           2001                                 WR8
WS Res 2   5000.     .1      1.
**  ---------------------------------------------------------------------------------
------------------------
ED
```

TABLES Input File for Example 7

```
COMM   TABLES Input File Tab7.DAT
COMM   Example 7
2NAT   0   1   1   0   0
2REG   0   1   0   0   0
2STO   0   1   1   2   3   Res 1   Res 2   Res 3
2DIV   0   1   1   1   3             WR3             WR5             WR6
2SHT   0   1   0   1   3             WR3             WR5             WR6
ENDF
```

		NAT CP1	NAT CP2	NAT CP3	NAT CP4	NAT CP5	REG CP1	REG CP2	REG CP3	REG CP4	REG CP5
1997	1	60.0	20.0	120.0	120.0	150.0	0.0	80.0	120.0	120.0	125.0
1997	2	60.0	20.0	120.0	120.0	150.0	0.0	80.0	120.0	120.0	125.0
1997	3	60.0	20.0	120.0	120.0	150.0	0.0	80.0	120.0	120.0	125.0
1997	4	120.0	90.0	240.0	460.0	680.0	0.0	210.0	240.0	310.0	130.0
1997	5	120.0	90.0	240.0	460.0	680.0	0.0	210.0	240.0	310.0	130.0
1997	6	120.0	90.0	240.0	460.0	680.0	0.0	210.0	240.0	310.0	130.0
1997	7	10.0	0.0	30.0	40.0	50.0	0.0	10.0	30.0	40.0	50.0
1997	8	10.0	0.0	30.0	40.0	50.0	0.0	10.0	30.0	40.0	50.0
1997	9	10.0	0.0	30.0	40.0	50.0	0.0	10.0	30.0	40.0	50.0
1997	10	10.0	0.0	30.0	40.0	50.0	0.0	50.0	70.0	80.0	90.0
1997	11	10.0	0.0	30.0	40.0	50.0	0.0	50.0	70.0	80.0	90.0
1997	12	10.0	0.0	30.0	40.0	50.0	0.0	50.0	70.0	80.0	90.0
1998	1	60.0	20.0	120.0	120.0	150.0	0.0	80.0	120.0	120.0	125.0
1998	2	60.0	20.0	120.0	120.0	150.0	0.0	80.0	120.0	120.0	125.0
1998	3	60.0	20.0	120.0	120.0	150.0	60.0	20.0	120.0	120.0	125.0
1998	4	300.0	100.0	500.0	600.0	900.0	300.0	100.0	500.0	230.0	130.0
1998	5	300.0	100.0	500.0	600.0	900.0	300.0	100.0	500.0	230.0	130.0
1998	6	300.0	100.0	500.0	600.0	900.0	300.0	100.0	500.0	230.0	130.0
1998	7	10.0	0.0	30.0	40.0	50.0	10.0	0.0	30.0	40.0	50.0
1998	8	10.0	0.0	30.0	40.0	50.0	10.0	0.0	30.0	40.0	50.0
1998	9	10.0	0.0	30.0	40.0	50.0	10.0	0.0	30.0	40.0	50.0
1998	10	10.0	0.0	30.0	40.0	50.0	10.0	0.0	30.0	40.0	50.0
1998	11	10.0	0.0	30.0	40.0	50.0	10.0	0.0	30.0	40.0	50.0
1998	12	10.0	0.0	30.0	40.0	50.0	10.0	0.0	30.0	40.0	50.0

Year	Month	STO Res 1	STO Res 2	STO Res 3	DIV WR3	DIV WR5	DIV WR6	SHT WR3	SHT WR5	SHT WR6
1997	1	4920.0	4940.0	7440.0	25.0	60.0	200.0	125.0	0.0	0.0
1997	2	4840.0	4940.0	6820.0	25.0	60.0	260.0	125.0	0.0	0.0
1997	3	4760.0	4940.0	6200.0	25.0	60.0	260.0	125.0	0.0	0.0
1997	4	4800.0	4880.0	5670.0	400.0	120.0	260.0	0.0	0.0	0.0
1997	5	4840.0	4880.0	5080.0	400.0	120.0	320.0	0.0	0.0	0.0
1997	6	4880.0	4880.0	4490.0	400.0	120.0	320.0	0.0	0.0	0.0
1997	7	4700.0	4990.0	3860.0	0.0	10.0	320.0	50.0	0.0	0.0
1997	8	4520.0	4990.0	3340.0	0.0	10.0	210.0	50.0	0.0	0.0
1997	9	4340.0	4990.0	2820.0	0.0	10.0	210.0	50.0	0.0	0.0
1997	10	4160.0	4950.0	2300.0	0.0	10.0	210.0	50.0	0.0	0.0
1997	11	3980.0	4950.0	1740.0	0.0	10.0	250.0	50.0	0.0	0.0
1997	12	3800.0	4950.0	1180.0	0.0	10.0	250.0	50.0	0.0	0.0
1998	1	3720.0	4940.0	570.0	25.0	60.0	250.0	125.0	0.0	0.0
1998	2	3640.0	4890.0	0.0	25.0	60.0	210.0	125.0	0.0	50.0
1998	3	3440.0	4690.0	0.0	25.0	0.0	0.0	125.0	60.0	310.0
1998	4	3310.0	4490.0	0.0	400.0	70.0	0.0	0.0	230.0	510.0
1998	5	3180.0	4290.0	0.0	400.0	70.0	0.0	0.0	230.0	710.0
1998	6	3050.0	4090.0	0.0	400.0	70.0	0.0	0.0	230.0	910.0
1998	7	2850.0	3890.0	0.0	0.0	0.0	0.0	50.0	10.0	1110.0
1998	8	2650.0	3690.0	0.0	0.0	0.0	0.0	50.0	10.0	1310.0
1998	9	2450.0	3490.0	0.0	0.0	0.0	0.0	50.0	10.0	1510.0
1998	10	2250.0	3290.0	0.0	0.0	0.0	0.0	50.0	10.0	1710.0
1998	11	2050.0	3090.0	0.0	0.0	0.0	0.0	50.0	10.0	1910.0
1998	12	1850.0	2890.0	0.0	0.0	0.0	0.0	50.0	10.0	2110.0

Example 8

The purpose of Example 8 is to illustrate the use of the evaporation allocation EA record to model a reservoir owned by multiple entities.

WRAP-SIM Input File for Example 8

```
T1 Evaporation Allocation EA Record Example 8 - File Exam8.dat
**
** The allocation of storage capacity and net evaporation-precipitation
** volume is illustrated with this simple data set.  Res-A, Res-B, and
** Res-B are "computational" component reservoirs representing a single
** actual reservoir owned/shared by three water supply entities.  The
** three component reservoirs have a common storage-area relationship
** which is provided as SV/SA records assigned to Res-A.
**
FO    -1      -1      -1
JD     2    1990       1      -1      -1
**
CP    CP1
**
WR    CP1  120000              1                          WR-1
WS Res-A  200000
1
**
WR    CP1  120000              2                          WR-2
WS Res-B  200000
1      -1
**
WR    CP1  120000              3                          WR-3
WS Res-C  100000
1      -1
**
** Allocation methods 2 and 3 (EA record field 3) uses the last-computed end-of-
month storage for the other
** component reservoirs when determining water surface area. For the more junior
reservoir storage rights, the
** end-of-month storage, which is not yet computed, is approximated as
beginning-of-month storage. The following
** records allow the net evaporation-precipitation computations to be repeated at
the end of the water rights loop.
** Method 1 (EA record field 3) accumulates storage and evaporation-
precipitation volumes, while considering only
** more senior component reservoirs. Thus, the following WR/WS records should
not be used with method 1.
**
**WR    CP1                     4                          WR-1a
**WS Res-A  200000
1
**
**WR    CP1                     5                          WR-2a
**WS Res-B  200000
1      -1
**
**WR    CP1                     6                          WR-3a
```

```
**WS Res-C  100000
1      -1
**
SV Res-A       0 100000  200000  400000  500000
SA             0  10000   20000   40000   50000
**
EA    1      3  Res-A   Res-B   Res-C
EF                0.4     0.4     0.2
**
** This EF record allocates the evaporation-precipitation in proportion to
** storage capacity. EF records are used only with method 3 (EA record field 3).
**
ED
**
IN   CP1   1990 100000  100000  100000       0       0       0       0       0
0   10000   10000   10000
EV   CP1   1990    0.2     0.2     0.2     0.2     0.2     0.2     0.2     0.2
0.2    0.2     0.2     0.2
**
IN   CP1   1991  20000   20000   20000  500000  500000  500000       0       0
0   10000   20000   50000
EV   CP1   1991    0.5     0.5     0.5     0.5     0.5     0.5     0.5     0.5
0.5    0.5     0.5     0.5
**
```

TABLES Input File for Example 8

```
COMM  TABLES Input File Tab8.DAT
2SWR   1
2SCP   1
ENDF
```

TABLES Output File for Example 8

MONTHLY SUMMARY TABLE FOR WATER RIGHT WR-1

YEAR	MONTH	TARGET DIVERSION (AC-FT)	AVAILABLE STREAMFLOW (ACRE-FEET)	ACTUAL DIVERSION (AC-FT)	STREAMFLOW DEPLETION (ACRE-FEET)	SHORTAGE (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	SYSTEM RELEASES (ACRE-FEET)
1990	1	10000.0	100000.0	10000.0	14000.0	0.0	200000.0	4000.0	0.0
1990	2	10000.0	100000.0	10000.0	14000.0	0.0	200000.0	4000.0	0.0
1990	3	10000.0	100000.0	10000.0	14000.0	0.0	200000.0	4000.0	0.0
1990	4	10000.0	0.0	10000.0	0.0	0.0	186055.8	3944.2	0.0
1990	5	10000.0	0.0	10000.0	0.0	0.0	172428.3	3627.5	0.0
1990	6	10000.0	0.0	10000.0	0.0	0.0	159111.3	3317.0	0.0
1990	7	10000.0	0.0	10000.0	0.0	0.0	146098.6	3012.7	0.0
1990	8	10000.0	0.0	10000.0	0.0	0.0	133384.2	2714.4	0.0
1990	9	10000.0	0.0	10000.0	0.0	0.0	120962.1	2422.1	0.0
1990	10	10000.0	10000.0	10000.0	10000.0	0.0	118786.6	2175.4	0.0
1990	11	10000.0	10000.0	10000.0	10000.0	0.0	116813.2	1973.5	0.0
1990	12	10000.0	10000.0	10000.0	10000.0	0.0	115037.6	1775.6	0.0
1991	1	10000.0	20000.0	10000.0	20000.0	0.0	120967.6	4070.0	0.0
1991	2	10000.0	20000.0	10000.0	20000.0	0.0	127056.1	3911.5	0.0
1991	3	10000.0	20000.0	10000.0	20000.0	0.0	133296.7	3759.4	0.0
1991	4	10000.0	500000.0	10000.0	80252.6	0.0	200000.0	3549.3	0.0
1991	5	10000.0	500000.0	10000.0	20000.0	0.0	200000.0	10000.0	0.0

```
1991     6       500000.0        20000.0     200000.0        10000.0          0.0
10000.0       10000.0              0.0
1991     7            0.0            0.0     180198.0         9802.0          0.0
10000.0       10000.0              0.0
1991     8            0.0            0.0     161468.1         8730.0          0.0
10000.0       10000.0              0.0
1991     9            0.0            0.0     143757.4         7710.6          0.0
10000.0       10000.0              0.0
1991    10        10000.0        10000.0     136917.0         6840.4          0.0
10000.0       10000.0              0.0
1991    11        20000.0        20000.0     140706.0         6211.0          0.0
10000.0       10000.0              0.0
1991    12        50000.0        50000.0     174697.3         6008.6          0.0
10000.0       10000.0              0.0
MEAN             82083.3        13843.9     157822.6         4898.1          0.0
10000.0       10000.0              0.0
----------------------------------------------------------------------------------
------------------------------------
```

MONTHLY SUMMARY TABLE FOR WATER RIGHT WR-2

YEAR	MONTH	TARGET DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	AVAILABLE STREAMFLOW DIVERSION (ACRE-FEET)	STREAMFLOW DEPLETION (ACRE-FEET)	SHORTAGE (AC-FT)	EOP STORAGE (AC-FT)	EVAPORATION (AC-FT)	SYSTEM RELEASES (ACRE-FEET)
1990	1	10000.0	10000.0	86000.0	14000.0	0.0	200000.0	4000.0	0.0
1990	2	10000.0	10000.0	86000.0	14000.0	0.0	200000.0	4000.0	0.0
1990	3	10000.0	10000.0	86000.0	14000.0	0.0	200000.0	4000.0	0.0
1990	4	10000.0	10000.0	0.0	0.0	0.0	186111.3	3888.7	0.0
1990	5	10000.0	10000.0	0.0	0.0	0.0	172538.2	3573.2	0.0
1990	6	10000.0	10000.0	0.0	0.0	0.0	159274.2	3263.9	0.0
1990	7	10000.0	10000.0	0.0	0.0	0.0	146313.4	2960.9	0.0
1990	8	10000.0	10000.0	0.0	0.0	0.0	133649.6	2663.8	0.0
1990	9	10000.0	10000.0	0.0	0.0	0.0	121277.0	2372.6	0.0
1990	10	10000.0	10000.0	0.0	0.0	0.0	109150.1	2126.9	0.0
1990	11	10000.0	10000.0	0.0	0.0	0.0	97224.3	1925.8	0.0
1990	12	10000.0	10000.0	0.0	0.0	0.0	85495.6	1728.6	0.0
1991	1	10000.0	10000.0	0.0	0.0	0.0	71565.0	3930.7	0.0
1991	2	10000.0	10000.0	0.0	0.0	0.0	57791.2	3773.8	0.0
1991	3	10000.0	10000.0	0.0	0.0	0.0	44168.1	3623.1	0.0
1991	4	10000.0	10000.0	419747.4	170048.3	0.0	200000.0	4216.3	0.0
1991	5	10000.0	10000.0	480000.0	20000.0	0.0	200000.0	10000.0	0.0
1991	6	10000.0	10000.0	480000.0	20000.0	0.0	200000.0	10000.0	0.0
1991	7	10000.0	10000.0	0.0	0.0	0.0	180394.1	9605.9	0.0
1991	8	10000.0	10000.0	0.0	0.0	0.0	161849.6	8544.5	0.0
1991	9	10000.0	10000.0	0.0	0.0	0.0	144314.3	7535.3	0.0
1991	10	10000.0	10000.0	0.0	0.0	0.0	127640.6	6673.7	0.0
1991	11	10000.0	10000.0	0.0	0.0	0.0	111590.1	6050.5	0.0

```
1991   12            0.0          0.0      95739.9      5850.1          0.0
10000.0      10000.0            0.0
MEAN              68239.5      10502.0     141920.3      4846.2          0.0
10000.0      10000.0            0.0
--------------------------------------------------------------------------------
------------------------------------
```

MONTHLY SUMMARY TABLE FOR WATER RIGHT WR-3

```
--------------------------------------------------------------------------------
------------------------------------
                AVAILABLE    STREAMFLOW      EOP                      SYSTEM
TARGET        ACTUAL
YEAR   MONTH   STREAMFLOW    DEPLETION     STORAGE   EVAPORATION     RELEASES
DIVERSION     DIVERSION     SHORTAGE
                (ACRE-FEET)   (ACRE-FEET)   (AC-FT)      (AC-FT)     (ACRE-FEET)
(AC-FT)       (AC-FT)       (AC-FT)
--------------------------------------------------------------------------------
------------------------------------
1990    1        72000.0      12000.0     100000.0      2000.0          0.0
10000.0      10000.0            0.0
1990    2        72000.0      12000.0     100000.0      2000.0          0.0
10000.0      10000.0            0.0
1990    3        72000.0      12000.0     100000.0      2000.0          0.0
10000.0      10000.0            0.0
1990    4            0.0          0.0      88079.5      1920.5          0.0
10000.0      10000.0            0.0
1990    5            0.0          0.0      76316.4      1763.1          0.0
10000.0      10000.0            0.0
1990    6            0.0          0.0      64707.7      1608.8          0.0
10000.0      10000.0            0.0
1990    7            0.0          0.0      53250.2      1457.5          0.0
10000.0      10000.0            0.0
1990    8            0.0          0.0      41940.9      1309.3          0.0
10000.0      10000.0            0.0
1990    9            0.0          0.0      30776.9      1164.0          0.0
10000.0      10000.0            0.0
1990   10            0.0          0.0      19735.5      1041.4          0.0
10000.0      10000.0            0.0
1990   11            0.0          0.0       8794.5       941.0          0.0
10000.0      10000.0            0.0
1990   12            0.0          0.0          0.0       846.7          0.0
10000.0       7947.8       2052.2
1991    1            0.0          0.0          0.0          0.0          0.0
10000.0          0.0      10000.0
1991    2            0.0          0.0          0.0          0.0          0.0
10000.0          0.0      10000.0
1991    3            0.0          0.0          0.0          0.0          0.0
10000.0          0.0      10000.0
1991    4       249699.2     112887.3     100000.0      2887.3          0.0
10000.0      10000.0            0.0
1991    5       460000.0      15000.0     100000.0      5000.0          0.0
10000.0      10000.0            0.0
1991    6       460000.0      15000.0     100000.0      5000.0          0.0
10000.0      10000.0            0.0
```

```
1991     7              0.0              0.0        85270.7        4729.3          0.0
10000.0       10000.0            0.0
1991     8              0.0              0.0        71069.4        4201.2          0.0
10000.0       10000.0            0.0
1991     9              0.0              0.0        57370.3        3699.1          0.0
10000.0       10000.0            0.0
1991    10              0.0              0.0        44099.8        3270.5          0.0
10000.0       10000.0            0.0
1991    11              0.0              0.0        31139.3        2960.5          0.0
10000.0       10000.0            0.0
1991    12              0.0              0.0        18278.6        2860.8          0.0
10000.0       10000.0            0.0
MEAN                57737.5          7453.6        53784.6        2194.2          0.0
10000.0        8664.5         1335.5
-----------------------------------------------------------------------------------
-----------------------------------
```

MONTHLY SUMMARY TABLE FOR CONTROL POINT CP1

YEAR	MONTH	NATURALIZED STREAMFLOW (ACRE-FEET)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (ACRE-FEET)	UNAPPROPRIATED FLOW (ACRE-FEET)	EOP STORAGE (AC-FT)	REGULATED STREAMFLOW EVAPORATION (ACRE-FEET)	ACTUAL STREAMFLOW DIVERSION (AC-FT)	DIVERSION DIVERSION (AC-FT)	DIVERSION SHORTAGE (AC-FT)
1990	1	100000.0	0.0	40000.0	60000.0	500000.0	10000.0	60000.0	30000.0	0.0
1990	2	100000.0	0.0	40000.0	60000.0	500000.0	10000.0	60000.0	30000.0	0.0
1990	3	100000.0	0.0	40000.0	60000.0	500000.0	10000.0	60000.0	30000.0	0.0
1990	4	0.0	0.0	0.0	0.0	460246.6	9753.4	0.0	30000.0	0.0
1990	5	0.0	0.0	0.0	0.0	421282.9	8963.7	0.0	30000.0	0.0
1990	6	0.0	0.0	0.0	0.0	383093.2	8189.7	0.0	30000.0	0.0
1990	7	0.0	0.0	0.0	0.0	345662.2	7431.1	0.0	30000.0	0.0
1990	8	0.0	0.0	0.0	0.0	308974.7	6687.5	0.0	30000.0	0.0
1990	9	0.0	0.0	0.0	0.0	273016.0	5958.7	0.0	30000.0	0.0
1990	10	10000.0	0.0	10000.0	0.0	247672.3	5343.7	0.0	30000.0	0.0
1990	11	10000.0	0.0	10000.0	0.0	222832.0	4840.3	0.0	30000.0	0.0
1990	12	10000.0	0.0	10000.0	0.0	200533.3	4350.9	0.0	27947.8	2052.2
1991	1	20000.0	0.0	20000.0	0.0	192532.6	8000.7	0.0	20000.0	10000.0
1991	2	20000.0	0.0	20000.0	0.0	184847.3	7685.3	0.0	20000.0	10000.0
1991	3	20000.0	0.0	20000.0	0.0	177464.8	7382.5	0.0	20000.0	10000.0
1991	4	500000.0	0.0	363188.2	136811.8	500000.0	10652.9	136811.8	30000.0	0.0
1991	5	500000.0	0.0	55000.0	445000.0	500000.0	25000.0	445000.0	30000.0	0.0
1991	6	500000.0	0.0	55000.0	445000.0	500000.0	25000.0	445000.0	30000.0	0.0
1991	7	0.0	0.0	0.0	0.0	445862.8	24137.2	0.0	30000.0	0.0
1991	8	0.0	0.0	0.0	0.0	394387.1	21475.7	0.0	30000.0	0.0
1991	9	0.0	0.0	0.0	0.0	345442.0	18945.1	0.0	30000.0	0.0
1991	10	10000.0	0.0	10000.0	0.0	308657.4	16784.6	0.0	30000.0	0.0
1991	11	20000.0	0.0	20000.0	0.0	283435.3	15222.0	0.0	30000.0	0.0

```
1991  12       50000.0        0.0        50000.0        0.0        288715.8
14719.5        0.0        30000.0        0.0
MEAN           82083.3        0.0        31799.5        50283.8        353527.5
11938.5        50283.8        28664.5        1335.5
----------------------------------------------------------------------------------
----------------------------------------
```

An *"Introduction to Appendices G and H"* is presented at the beginning of Appendix G. The examples illustrate the format and content of the input and output. They also provide a starting point for creating other data sets containing other features of interest to model users. Model users should experiment with simple data sets to become proficient with various modeling features prior to application to complex real world river basins. Model results with simplified data are easily trackable. Users can compare computer results with manual computational checks to confirm that the programs work as expected.

Four simplified examples are provided to illustrate *WRAP-HYD* input and output data sets. Examples 9, 10, and 11 demonstrate basic *AS/FA/RS/SC/CI* record streamflow adjustment features and also include *EP* record evaporation-precipitation manipulations. Example 12 focuses on distribution of streamflows from gaged to ungaged control points. *IN* records for Example 12 are provided alternatively as a standard-format INF file and an old-format HYD file. Examples 9 and 10 are identical except for the format of the input and output. Example 10 is included to further illustrate input/output format options. *IN/EV* records in Examples 9 and 11 are input in the optional control point grouping format and output in standard format. Example 10 uses the columnar table format for the streamflow input file rather than *IN* records.

Example 9

The Example 9 river basin configuration is represented by four control points (labeled CP-1, CP-2, CP-3, CP-4) representing actual locations in the stream system. Two other control points (CP1E and CP2P) serve as identifiers for evaporation (CP1E) and precipitation (CP1P) data sets for reservoir Res located at CP-1. An input file with filename Exam9.DAT contains:

- file option *FO*, job control *JC*, and control point *CP* records

- an *EP* record activating an evaporation-precipitation combining operation

- specifications (*AS* records) and information for adjusting the flows for a *FA* record series of inflows/outflows and for the effects of a reservoir (*RS* and *SC* records)

Evaporation and precipitation depths (*EV* records) are provided in file Exam9.EVA with the control point identifiers CP1E and CP1P, respectively. The same sets of 12 monthly evaporation and precipitation depths are repeated for each of the three years of the period-of-analysis. An *EP* record in the DAT file specifies that the precipitation be subtracted from the evaporation, and that the resulting net evaporation-precipitation depths be assigned to control point CP-1. The output file Ex9out.EVA contains only the computed *EV* records for CP-1. *EV* records for all other control points are omitted from the output file as specified in field 12 of the *CP* records. The net evaporation-precipitation depths are also used in the reservoir evaporation-precipitation computations performed in adjusting streamflows as instructed by the *RS* record.

Observed streamflows (*IN* records) are provided as an inflow file with the filename Exam9.INF. The streamflows are adjusted as specified by *AS* records using data from *FA* and *RS/SC* records. Each adjustment occurs at a specified control point and all downstream

locations. Channel losses are considered in cascading the adjustments through the reach below CP-3. Streamflows at CP-2 and downstream control points CP-3 and CP-4 are adjusted based on inflows/outflows provided on *FA* records for all three years of the period-of-analysis. Streamflows at CP-1 and downstream control points CP-3 and CP-4 are adjusted for the effects of the reservoir at CP-1 following the specifications from the *RS* record. The default selection of components to include in the reservoir adjustments is adopted. The streamflow adjustments for the effects of the reservoir cover the last two years of the three-year hydrologic period-of-analysis.
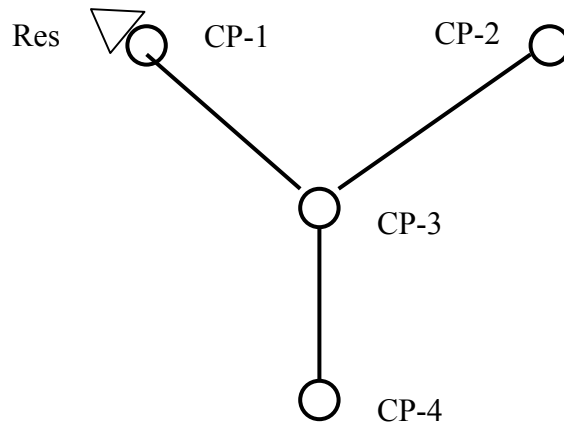
Control Point System Schematic for Example 9

The configuration of the river basin system is shown in the above schematic. The three input files and four output files are presented on the following pages. The filenames (root.extension) of the input files have a root1 of *Exam9* and extensions *DAT*, *INF*, and *EVA*. The output filenames have a root2 of Ex9out and extensions *MSS*, *OUT*, *INF* and *EVA*. The output *WRAP-HYD* output files Ex9out.INF and Ex9out.EVA containing the final adjusted *IN* and *EV* records are designed to serve as input files files for *WRAP-SIM*. The message file Ex9out.MSS tracks the program's progress in reading the input files, performing computations, and developing output files. The output file Ex9out.OUT contains two tables. The first table, which is activated by an entry in *RS* record field 8, shows the intermediate results of determining streamflow adjustments for the effects of the reservoir. The second table in the Ex8out.OUT file is a tabulation of the final adjusted streamflows as specified by *JC* record field 9. The numbers are the same as those on the *IN* records in the Ex8out.INF file. However, the columnar format facilitates transporting the data to a spreadsheet program such as *Microsoft Excel* for plotting or various computational manipulations. Example 10 reads the streamflows in this columnar format and converts them to the standard *IN* record format. Examples 9 and 10 are identical except for input and output data format options.

WRAP-HYD DAT Input File for Example 9

```
**   WRAP-HYD Input File Exam9.DAT
**   Example 9 from Appendix H of WRAP Reference Manual
**
FO     1       1                          1       1       1
JC     3    1991       1       2       2       1       0       1
**
**   CP records for four actual control points (CP-1, CP-2, CP-3, and CP-4) and
**   evaporation (CP1E) and precipitation (CP1P) data set identifiers for CP-1.
**
CP  CP1E                          2    none
CP  CP1P                          2    none                                      4
CP  CP-1    CP-3                           none  10000.
CP  CP-2    CP-3                           none                          2
CP  CP-3    CP-4                           none              0.3         2
CP  CP-4     OUT                  2    CP-3  none                        2
**
**   The net evaporation-precipitation for CP-1 is computed by subtracting the
**   precipitation assigned to CP1P from the evaporation entered with CP1E.
**
EP  CP-1    CP1E    1.0    CP1P   -1.0
**
**   FA record adjustments at CP-2 and downstream control points for three years.
**
AS  CP-2                                        3
FA   100     100     100     100     100     100    -100    -100    -100       0       0       0
FA   100     100     100     100     100     100    -100    -100    -100       0       0       0
FA   100     100     100     100     100     100    -100    -100    -100       0       0       0
**
**   Reservoir Res-A adjustments at CP-1 and downstream control points for two years.
**
AS  CP-1    1992    1993       2                3
RS  Res                                         1    2000     0.1     1.0            2000
SC  2000    2000    1500    1000     500       0    1000    2000    3000    2500    2000    1500
SC  2000    2000    1500    1000     500       0    1000    2000    3000    2500    2000    1500
**
ED
```

WRAP-HYD INF Input File for Example 9

```
**   WRAP-HYD Input File Exam9.INF
**   Example 9 from Appendix H of WRAP Reference Manual
**
IN  CP-1    1996    4000    4000    4000    4000    4000    4000    4000    4000    4000    4000    4000    4000
IN  CP-1    1997    3600     400      20     160     140      50       0     210    1400    2200    3100    3200
IN  CP-1    1998    6500    6500    6500    6500    6500    6500    7500    7500    7500    7500    7500    7500
**
IN  CP-2    1996    5000    5000    5000    5000    5000    5000    5000    5000    5000    5000    5000    5000
IN  CP-2    1997    4200     600      50     250     320      80      10     390    2300    3100    4800    4400
IN  CP-2    1998    7100    8200    7000    7200    6900    5500    6700    6500    7300    8100    7900    8300
**
IN  CP-3    1996    6000    6000    6000    6000    6000    6000    6000    6000    6000    6000    6000    6000
IN  CP-3    1997    5500     650     520     560     520     440      90     520    3500    4200    6500    7500
IN  CP-3    1998    7600    9600    8200    8200    7300    7300    7300    7300    8600    8600    8600    8600
**
IN  CP-4    1996    8000    8000    8000    8000    8000    8000    8000    8000    8000    8000    8000    8000
IN  CP-4    1997    7200    1200    1400    2200    1600    1200     850    1400    5200    5700    7200    9200
IN  CP-4    1998    9300   12500    8500    9700    8200    7900    7600    8300    9700    9100    8900   10500
```

WRAP-HYD EVA Input File for Example 9

```
**   WRAP-HYD Input File Exam9.EVA
**   Example 8 from Appendix H of WRAP Reference Manual
**   Evaporation (CP1E) and Precipitation (CP1P) for Control Point CP-1 in feet
**
EV  CP1E19911993     1.5     1.5     1.5     0.3     0.3     0.3     0.2     0.2     0.2     1.4     1.4     1.4
EV  CP1P19911993     0.5     0.5     0.5     0.8     0.8     0.8     0.1     0.1     0.1     1.4     1.4     1.4
```

WRAP-HYD Message File for Example 9

```
WRAP-HYD MESSAGE FILE

 *** Starting to read file Exam9.DAT
 *** JC record was read.
 *** Starting to read CP records.
 *** Finished reading CP records.
 *** Counting EP records. (They will be reread later.)
 *** Finished reading file Exam8.DAT
 **********************************************************
Number of CP, SV/SA, and EP records read from DAT file.
        6 control point CP records
        3 control points with streamflows read as input
        0 pairs of storage-area table SV/SA records
        1 evap-precip rate adjustment EP records
 **********************************************************
 *** Starting to read IN and/or EV records in JC(1),JC(2)=2 format.
 *** Reordering IN records and multiplying by factors on CP records.
 *** Finished reading IN records from INF file in optional format [JC(1)=2].
 *** Starting to read EV records from EVA file in optional format [JC(2)=2].
 *** Reordering EV records and multiplying by factors on CP records.
 *** Finished reading IN and/or EV records.
 *** Starting to read EP records.
 *** Finished developing EV records as specified by EP records.
 *** Starting to adjust flows as specified by AS and/or EQ records.
 *** Finished adjusting flows as specified by AS and/or EQ records.
 *** Starting to write IN and/or EV records to INF/EVA files.
 *** Starting to write streamflows in columnar format.

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

WRAP-HYD EVA Output File for Example 9

```
WRAP-HYD Output File Ex9out.EVA


EV CP-1   1991   1.00   1.00   1.00  -0.50  -0.50  -0.50   0.10   0.10   0.10   0.00   0.00   0.00
EV CP-1   1992   1.00   1.00   1.00  -0.50  -0.50  -0.50   0.10   0.10   0.10   0.00   0.00   0.00
EV CP-1   1993   1.00   1.00   1.00  -0.50  -0.50  -0.50   0.10   0.10   0.10   0.00   0.00   0.00
```

WRAP-HYD FLO Output File for Example 9

```
WRAP-HYD Output File Ex9out.FLO

IN  CP-1   1991  1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0
IN  CP-2   1991  1100.0 1100.0 1100.0 1100.0 1100.0 1100.0  900.0  900.0  900.0 1000.0 1000.0 1000.0
IN  CP-3   1991  3100.0 3100.0 3100.0 3100.0 3100.0 3100.0 2900.0 2900.0 2900.0 3000.0 3000.0 3000.0
IN  CP-4   1991  3070.0 3070.0 3070.0 3070.0 3070.0 3070.0 2930.0 2930.0 2930.0 3000.0 3000.0 3000.0
IN  CP-1   1992   710.0  710.0  183.8    0.0    0.0    0.0 1507.5 1522.5 1537.5   13.8   11.3    8.8
IN  CP-2   1992   600.0  600.0  600.0  600.0  600.0  600.0  400.0  400.0  400.0  500.0  500.0  500.0
IN  CP-3   1992  2310.0 2310.0 1783.8 1600.0 1600.0 1600.0 2907.5 2922.5 2937.5 1513.8 1511.3 1508.8
IN  CP-4   1992  2217.0 2217.0 1848.6 1720.0 1720.0 1720.0 2635.3 2645.8 2656.3 1659.6 1657.9 1656.1
IN  CP-1   1993   675.0  200.0    0.0    0.0    0.0    0.0 1005.0 1015.0 1025.0    0.0    0.0    0.0
IN  CP-2   1993   100.0  100.0  100.0  100.0  100.0  100.0    0.0    0.0    0.0    0.0    0.0    0.0
IN  CP-3   1993   775.0  300.0  100.0  100.0  100.0  100.0 1005.0 1015.0 1025.0    0.0    0.0    0.0
IN  CP-4   1993   542.5  210.0   70.0   70.0   70.0   70.0  703.5  710.5  717.5    0.0    0.0    0.0
```

WRAP-HYD OUT Output File for Example 9

```
WRAP-HYD Output File Ex9out.OUT

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

-------------------------------------------------------------------------------
                                     RS(1)&RS(2) RS(3)    RS(4)    RS(5)
           Ending    Mean   Runoff Storage               Precip   Site     Total
Year Month Storage   Area    Depth  Change     Spill     -Evap    Runoff
Adjustment
           (ac-ft)  (acres) (feet) (ac-ft)    (ac-ft)   (ac-ft)  (ac-ft)  (ac-ft)
-------------------------------------------------------------------------------
1992   1   2000.0   200.0   0.050     0.0       0.0     200.0    10.0      210.0
1992   2   2000.0   200.0   0.050     0.0       0.0     200.0    10.0      210.0
1992   3   1500.0   175.0   0.050  -500.0       0.0     175.0     8.8     -316.3
1992   4   1000.0   125.0   0.050  -500.0       0.0     -62.5     6.3     -556.3
1992   5    500.0    75.0   0.050  -500.0       0.0     -37.5     3.8     -533.8
1992   6      0.0    25.0   0.050  -500.0       0.0     -12.5     1.3     -511.3
1992   7   1000.0    50.0   0.050  1000.0       0.0       5.0     2.5     1007.5
1992   8   2000.0   150.0   0.050  1000.0       0.0      15.0     7.5     1022.5
1992   9   3000.0   250.0   0.050  1000.0       0.0      25.0    12.5     1037.5
1992  10   2500.0   275.0   0.050     0.0     500.0       0.0    13.8     -486.3
1992  11   2000.0   225.0   0.050     0.0     500.0       0.0    11.3     -488.8
1992  12   1500.0   175.0   0.050  -500.0       0.0       0.0     8.8     -491.3
1993   1   2000.0   175.0   0.000   500.0       0.0     175.0     0.0      675.0
1993   2   2000.0   200.0   0.000     0.0       0.0     200.0     0.0      200.0
1993   3   1500.0   175.0   0.000  -500.0       0.0     175.0     0.0     -325.0
1993   4   1000.0   125.0   0.000  -500.0       0.0     -62.5     0.0     -562.5
1993   5    500.0    75.0   0.000  -500.0       0.0     -37.5     0.0     -537.5
1993   6      0.0    25.0   0.000  -500.0       0.0     -12.5     0.0     -512.5
1993   7   1000.0    50.0   0.000  1000.0       0.0       5.0     0.0     1005.0
1993   8   2000.0   150.0   0.000  1000.0       0.0      15.0     0.0     1015.0
1993   9   3000.0   250.0   0.000  1000.0       0.0      25.0     0.0     1025.0
1993  10   2500.0   275.0   0.000     0.0     500.0       0.0     0.0     -500.0
1993  11   2000.0   225.0   0.000     0.0     500.0       0.0     0.0     -500.0
1993  12   1500.0   175.0   0.000  -500.0       0.0       0.0     0.0     -500.0
                                   ------    ------    ------   ------   -------
Adjustment Means                     62.5      83.3      41.3     4.0      24.4
-------------------------------------------------------------------------------
```

Year	Mon	CP-1	CP-2	CP-3	CP-4
1991	1	1000.0	1100.0	3100.0	3070.0
1991	2	1000.0	1100.0	3100.0	3070.0
1991	3	1000.0	1100.0	3100.0	3070.0
1991	4	1000.0	1100.0	3100.0	3070.0
1991	5	1000.0	1100.0	3100.0	3070.0
1991	6	1000.0	1100.0	3100.0	3070.0
1991	7	1000.0	900.0	2900.0	2930.0
1991	8	1000.0	900.0	2900.0	2930.0
1991	9	1000.0	900.0	2900.0	2930.0
1991	10	1000.0	1000.0	3000.0	3000.0
1991	11	1000.0	1000.0	3000.0	3000.0
1991	12	1000.0	1000.0	3000.0	3000.0
1992	1	710.0	600.0	2310.0	2217.0
1992	2	710.0	600.0	2310.0	2217.0
1992	3	183.8	600.0	1783.8	1848.6
1992	4	0.0	600.0	1600.0	1720.0
1992	5	0.0	600.0	1600.0	1720.0
1992	6	0.0	600.0	1600.0	1720.0
1992	7	1507.5	400.0	2907.5	2635.3
1992	8	1522.5	400.0	2922.5	2645.8
1992	9	1537.5	400.0	2937.5	2656.3
1992	10	13.8	500.0	1513.8	1659.6
1992	11	11.3	500.0	1511.3	1657.9
1992	12	8.8	500.0	1508.8	1656.1
1993	1	675.0	100.0	775.0	542.5
1993	2	200.0	100.0	300.0	210.0
1993	3	0.0	100.0	100.0	70.0
1993	4	0.0	100.0	100.0	70.0
1993	5	0.0	100.0	100.0	70.0
1993	6	0.0	100.0	100.0	70.0
1993	7	1005.0	0.0	1005.0	703.5
1993	8	1015.0	0.0	1015.0	710.5
1993	9	1025.0	0.0	1025.0	717.5
1993	10	0.0	0.0	0.0	0.0
1993	11	0.0	0.0	0.0	0.0
1993	12	0.0	0.0	0.0	0.0

Example 10

Example 10 consists of repeating Example 9 using different input data options. The sole purpose of Example 10 is to further illustrate variations in input options. Numeric data for the majority of the input records in the files Exam10.DAT and Exam10.EVA are entered in comma-delimited format rather than the standard fixed-width-field format adopted in Example 9. The streamflows are entered in file Exam10.INF as columns of a table rather than as *IN* records. The output files Ex10out.INF and Ex10out.EVA are in standard *IN* and *EV* record format.

WRAP-HYD DAT Input File for Example 10

```
**  WRAP-HYD Input File Exam10.DAT
**  Example 10 from Appendix H of WRAP Reference Manual
**  Examples 9 and 10 are identical except for format options.
**
FO 1,1,,,,,1,1,
JC 3,1991,1,5,2,1,
**
**  CP records for four actual control points (CP-1, CP-2, CP-3, and CP-4) and
**  evaporation (CP1E) and precipitation (CP1P) data set identifiers for CP-1.
**
CP  CP1E                              2    none
CP  CP1P                              2    none                                    4
CP  CP-1    CP-3                                 none   10000.
CP  CP-2    CP-3                                 none                              2
CP  CP-3    CP-4                                 none              0.3             2
CP  CP-4     OUT                      2    CP-3  none                              2
**
**  The net evaporation-precipitation for CP-1 is computed by subtracting the
**  precipitation assigned to CP1P from the evaporation entered with CP1E.
**
EP  CP-1    CP1E     1.0     CP1P    -1.0
**
**  FA record adjustments at CP-2 and downstream control points for three years.
**
AS  CP-2,,,,,3
FA  100,100,100,100,100,100,-100,-100,-100,,,,
FA  100,100,100,100,100,100,-100,-100,-100,,,,
FA  100,100,100,100,100,100,-100,-100,-100,,,,
**
**  Reservoir Res-A adjustments at CP-1 and downstream control points for two years.
**
AS  CP-1 1992,1993,-2,,3,
RS   Res ,,,,,,2000,0.1,1.0,0.0,2000,
SC  CP-1  1992,2000,2000,1500,1000,500,0,1000,2000,3000,2500,2000,1500,
SC  CP-1  1993,2000,2000,1500,1000,500,0,1000,2000,3000,2500,2000,1500,
**
ED
```

WRAP-HYD EVA Input File for Example 10

```
**  WRAP-HYD Input File Exam10.EVA
**  Example 10 from Appendix J of WRAP Reference/Users Manual
**  Evaporation (CP1E) and Precipitation (CP1P) for Control Point CP-1 in feet
**
EV  CP1E19911993  1.5,1.5,1.5,0.3,0.3,0.3,0.2,0.2,0.2,1.4,1.4,1.4,
EV  CP1P19911993  0.5,0.5,0.5,0.8,0.8,0.8,0.1,0.1,0.1,1.4,1.4,1.4,
```

WRAP-HYD FLO Input File for Example 10

```
**   WRAP-HYD Input File Exam10.FLO
**   Example 10 from Appendix H of WRAP Reference Manual
**   Streamflows in Columnar Format
**

Year Mon    CP-1     CP-2     CP-3

1991   1  1000.0   1000.0   3000.0
1991   2  1000.0   1000.0   3000.0
1991   3  1000.0   1000.0   3000.0
1991   4  1000.0   1000.0   3000.0
1991   5  1000.0   1000.0   3000.0
1991   6  1000.0   1000.0   3000.0
1991   7  1000.0   1000.0   3000.0
1991   8  1000.0   1000.0   3000.0
1991   9  1000.0   1000.0   3000.0
1991  10  1000.0   1000.0   3000.0
1991  11  1000.0   1000.0   3000.0
1991  12  1000.0   1000.0   3000.0
1992   1   500.0    500.0   2000.0
1992   2   500.0    500.0   2000.0
1992   3   500.0    500.0   2000.0
1992   4   500.0    500.0   2000.0
1992   5   500.0    500.0   2000.0
1992   6   500.0    500.0   2000.0
1992   7   500.0    500.0   2000.0
1992   8   500.0    500.0   2000.0
1992   9   500.0    500.0   2000.0
1992  10   500.0    500.0   2000.0
1992  11   500.0    500.0   2000.0
1992  12   500.0    500.0   2000.0
1993   1     0.0      0.0      0.0
1993   2     0.0      0.0      0.0
1993   3     0.0      0.0      0.0
1993   4     0.0      0.0      0.0
1993   5     0.0      0.0      0.0
1993   6     0.0      0.0      0.0
1993   7     0.0      0.0      0.0
1993   8     0.0      0.0      0.0
1993   9     0.0      0.0      0.0
1993  10     0.0      0.0      0.0
1993  11     0.0      0.0      0.0
1993  12     0.0      0.0      0.0
```

WRAP-HYD Output File for Example 10

```
WRAP-HYD Output File Ex10out.EVA


EV  CP-1   1991   1.00   1.00   1.00   -0.50   -0.50   -0.50   0.10   0.10   0.10   0.00   0.00   0.00
EV  CP-1   1992   1.00   1.00   1.00   -0.50   -0.50   -0.50   0.10   0.10   0.10   0.00   0.00   0.00
EV  CP-1   1993   1.00   1.00   1.00   -0.50   -0.50   -0.50   0.10   0.10   0.10   0.00   0.00   0.00
```

WRAP-HYD Output File for Example 10

```
WRAP-HYD Output File Ex10out.INF

IN  CP-1  1991 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0 1000.0
IN  CP-2  1991 1100.0 1100.0 1100.0 1100.0 1100.0 1100.0  900.0  900.0  900.0 1000.0 1000.0 1000.0
IN  CP-3  1991 3100.0 3100.0 3100.0 3100.0 3100.0 3100.0 2900.0 2900.0 2900.0 3000.0 3000.0 3000.0
IN  CP-4  1991 3070.0 3070.0 3070.0 3070.0 3070.0 3070.0 2930.0 2930.0 2930.0 3000.0 3000.0 3000.0
IN  CP-1  1992  710.0  710.0  183.8    0.0    0.0    0.0 1507.5 1522.5 1537.5   13.8   11.3    8.8
IN  CP-2  1992  600.0  600.0  600.0  600.0  600.0  600.0  400.0  400.0  400.0  500.0  500.0  500.0
IN  CP-3  1992 2310.0 2310.0 1783.8 1600.0 1600.0 1600.0 2907.5 2922.5 2937.5 1513.8 1511.3 1508.8
IN  CP-4  1992 2217.0 2217.0 1848.6 1720.0 1720.0 1720.0 2635.3 2645.8 2656.3 1659.6 1657.9 1656.1
IN  CP-1  1993  675.0  200.0    0.0    0.0    0.0    0.0 1005.0 1015.0 1025.0    0.0    0.0    0.0
IN  CP-2  1993  100.0  100.0  100.0  100.0  100.0  100.0    0.0    0.0    0.0    0.0    0.0    0.0
IN  CP-3  1993  775.0  300.0  100.0  100.0  100.0  100.0 1005.0 1015.0 1025.0    0.0    0.0    0.0
IN  CP-4  1993  542.5  210.0   70.0   70.0   70.0   70.0  703.5  710.5  717.5    0.0    0.0    0.0
```

Example 11

The river basin configuration is represented by four control points (labeled CP-1, CP-2, CP-3, CP-4) located in series on the same stream. A reservoir with identifier RES-A is located at control point CP-2. A file with filename Exam11.DAT contains:

- file option *FO*, job control *JC*, and control point *CP* records

- *EP* records activating evaporation-precipitation combining operations

- specifications and information for adjusting the flows for a constant annual set of inflows/outflows (*CI* records), multiple-year series of inflows/outflows (*AS* and *FA* records), and the effects of reservoir RES-2 (*AS*, *RS*, *SC*, and *SV/SA* records)

Observed streamflows (*IN* records) are provided in an inflow file with the filename Exam11.INF. Evaporation and precipitation rates (*EV* records) for the reservoir adjustments are provided in the file Exam11.EVA. *WRAP-HYD* performs the evaporation-precipitation manipulations and streamflow adjustments and writes the resulting net evaporation-precipitation (*EV* records) and naturalized streamflows (*IN* records) to output files with filenames Ex11out.EVA and Ex11out.INF. The three input files (root1 of Exam11 and extensions DAT, INF, and EVA) and two output files (root2 of Ex11out and extensions INF and EVA) are presented on the following pages.

Net evaporation-precipitation data (*EV* records) for control points CP-1 and CP-2 are provided in file Exam10.EVA. An *EP* record in the DAT file specifies that the net evaporation-precipitation depths for CP-2 be computed by averaging the depths at CP-1 and CP-3. The output file Ex11out.EVA contains only the *EV* records for CP-1, CP-2, and CP-3.

The streamflows entered in the file Exam11.INF are adjusted as specified by *AS* records using data from *CI*, *FA*, and *RS/SC/SV/SA* records. All of the *RS* record defaults are adopted for the component adustments for the effects of the reservoir at CP-2. Each adjustment occurs at a specified control point and all downstream locations. After accumulating all adjustments, any negative streamflows are set to zero with a final *AS* record with negative flow 2 specified in field 7 and a constant adjustment of zero specified in fields 5 and 9.

WRAP-HYD DAT Input File for Example 11

```
T1  WRAP-HYD Input File Exam11.DAT
T2  Example 11 from Appendix H of WRAP Reference Manual
**
FO    1        1        0        0        1        0        1        1
JC    3     1996        2        2        2        1
**
CP  CP-1    CP-2
CP  CP-2    CP-3                                      NONE    10000                        0
CP  CP-3    CP-4
CP  CP-4                                              NONE                                 2
**
CI  CP-3      20       20       20       20       20       20
CI           -10      -20     -100       50       50       50
**
SV  RES-A      0      100      200      400      600      800     1000
SA             0       20       40       80      120      160      200
**
**  The net evaporation-precipitation EV records for CP-2 are developed by averaging the
**  net evaporation-precipitation depths from EV records for CP-1 and CP-3.
**
EP  CP-2    CP-1     1.0     CP-3     1.0
**
**  CI record adjustments at CP-3 and downstream control points repeated for each of three years.
**
AS  CP-3    1996     1998        3
**
**  FA record adjustments at CP-3 and downstream control points for three years.
**
AS  CP-3
FA   100      100      100     -100     -100     -100        0        0        0       50       50       50
FA   -40      -30      -30        0       20       20       50       50       50       50       80       80
FA    25        0        5       18       12      -18       15       26       19       15       12       20
**
**  Reservoir Res-A adjustments at CP-2 and downstream control points for two years.
**
AS  CP-2    1997     1998        2
RS  RES-A                                                800                                        800
SC   800      800      800      700      500      500      600      700      800      900      850      800
SC   800      800      800      750      750      750      760      770      780      790      800      800
**
**  FA record adjustments at CP-1 and downstream  control points for one year.
**
AS  CP-1    1997     1997
FA    10       10       10       20       20       20        0        0        0      -10      -30      -20
**
**  Any negative streamflows are set to zero with the negative amount subtracted the next-month.
**
AS  CP-1    1996     1998        4        0        2        0        0
**
ED
```


WRAP-HYD EVA Input File for Example 11

```
**   WRAP-HYD Input File Exam11.EVA
**   Example 11 from Appendix H of WRAP Reference Manual
**
EV  CP-1    1996    0.21    -0.12    0.15    -0.12    0.43    0.55    0.17    0.49    0.51    0.42    -0.08    0.13
EV  CP-1    1997    0.17     0.21    0.39     0.35    0.48    0.51    0.42    0.22    0.38    0.23     0.12    0.21
EV  CP-1    1998    0.34     0.12    0.36     0.38    0.42    0.32    0.24    0.18    0.52    0.46     0.39    0.38
**
EV  CP-3    1996    0.10     0.00    0.08    -0.10    0.52    0.41    0.02    0.01    0.25    0.09     0.06   -.05
EV  CP-3    1997    0.00     0.06    0.23     0.24    0.42    0.56    0.44    0.30    0.12    0.22     0.12    0.01
EV  CP-3    1998    0.12    -0.18    0.15     0.22    0.45    0.18    0.11    0.03    0.36    0.15     0.33    0.26
```

WRAP-HYD FLO Input File for Example 11

```
**    WRAP-HYD Input File Exam11.FLO
**    Example 11 from Appendix H of WRAP Reference Manual
**
IN  CP-1  1996   4000    4000    4000    4000    4000    4000    4000    4000    4000    4000    4000    4000
IN  CP-1  1997   3600     400      20     160     140      50       0     210    1400    2200    3100    3200
IN  CP-1  1998   6500    6500    6500    6500    6500    6500    7500    7500    7500    7500    7500    7500
**
IN  CP-2  1996   5000    5000    5000    5000    5000    5000    5000    5000    5000    5000    5000    5000
IN  CP-2  1997   4200     600      50     250     320      80      10     390    2300    3100    4800    4400
IN  CP-2  1998   7100    8200    7000    7200    6900    5500    6700    6500    7300    8100    7900    8300
**
IN  CP-3  1996   6000    6000    6000    6000    6000    6000    6000    6000    6000    6000    6000    6000
IN  CP-3  1997   5500     650     520     560     520     440      90     520    3500    4200    6500    7500
IN  CP-3  1998   7600    9600    8200    8200    7300    7300    7300    7300    8600    8600    8600    8600
**
IN  CP-4  1996   8000    8000    8000    8000    8000    8000    8000    8000    8000    8000    8000    8000
IN  CP-4  1997   7200    1200    1400    2200    1600    1200     850    1400    5200    5700    7200    9200
IN  CP-4  1998   9300   12500    8500    9700    8200    7900    7600    8300    9700    9100    8900   10500
```

WRAP-HYD FLO Output File for Example 11

```
WRAP-HYD Output File Ex11out.FLO

IN  CP-1  1996   4000.0   4000.0   4000.0   4000.0   4000.0   4000.0   4000.0   4000.0   4000.0   4000.0   4000.0   4000.0
IN  CP-2  1996   5000.0   5000.0   5000.0   5000.0   5000.0   5000.0   5000.0   5000.0   5000.0   5000.0   5000.0   5000.0
IN  CP-3  1996   6120.0   6120.0   6120.0   5920.0   5920.0   5920.0   5990.0   5980.0   5900.0   6100.0   6100.0   6100.0
IN  CP-4  1996   8120.0   8120.0   8120.0   7920.0   7920.0   7920.0   7990.0   7980.0   7900.0   8100.0   8100.0   8100.0
IN  CP-1  1997   3610.0    410.0     30.0    180.0    160.0     70.0      0.0    210.0   1400.0   2190.0   3070.0   3180.0
IN  CP-2  1997   4304.4    662.8    160.0    262.3    251.8    207.8    204.7    562.7   2509.5   3319.2   4846.0   4438.9
IN  CP-3  1997   5584.4    702.8    620.0    592.3    491.8    607.8    324.7    722.7   3659.5   4519.2   6676.0   7668.9
IN  CP-4  1997   7284.4   1252.8   1500.0   2232.3   1571.8   1367.8   1084.7   1602.7   5359.5   6019.2   7376.0   9368.9
IN  CP-1  1998   6500.0   6500.0   6500.0   6500.0   6500.0   6500.0   7500.0   7500.0   7500.0   7500.0   7500.0   7500.0
IN  CP-2  1998   7287.2   8321.6   7193.6   7354.6   7134.0   5657.5   6864.0   6641.6   7559.5   8332.9   8150.1   8535.2
IN  CP-3  1998   7832.2   9741.6   8418.6   8392.6   7566.0   7459.5   7469.0   7447.6   8778.5   8897.9   8912.1   8905.2
IN  CP-4  1998   9532.2  12641.6   8718.6   9892.6   8466.0   8059.5   7769.0   8447.6   9878.5   9397.9   9212.1  10805.2
```

WRAP-HYD EVA Output File for Example 11

```
WRAP-HYD Output File Ex11out.EVA

EV  CP-1  1996   0.21   -0.12    0.15   -0.12    0.43    0.55    0.17    0.49    0.51    0.42   -0.08    0.13
EV  CP-2  1996   0.31   -0.12    0.23   -0.22    0.95    0.96    0.19    0.50    0.76    0.51   -0.02    0.08
EV  CP-3  1996   0.10    0.00    0.08   -0.10    0.52    0.41    0.02    0.01    0.25    0.09    0.06   -0.05
EV  CP-1  1997   0.17    0.21    0.39    0.35    0.48    0.51    0.42    0.22    0.38    0.23    0.12    0.21
EV  CP-2  1997   0.17    0.27    0.62    0.59    0.90    1.07    0.86    0.52    0.50    0.45    0.24    0.22
EV  CP-3  1997   0.00    0.06    0.23    0.24    0.42    0.56    0.44    0.30    0.12    0.22    0.12    0.01
EV  CP-1  1998   0.34    0.12    0.36    0.38    0.42    0.32    0.24    0.18    0.52    0.46    0.39    0.38
EV  CP-2  1998   0.46   -0.06    0.51    0.60    0.87    0.50    0.35    0.21    0.88    0.61    0.72    0.64
EV  CP-3  1998   0.12   -0.18    0.15    0.22    0.45    0.18    0.11    0.03    0.36    0.15    0.33    0.26
```

Example 12

The system of Figure 4-1 discussed in Chapter 4 is adopted for the final example. Naturalized streamflows at gaged control points J, K, L, M, and N, stored in *WRAP-HYD* input file Exam12.INF, are used to compute naturalized flows at ungaged control points I, II, III, and IV. The *WRAP-HYD* input data are provided in files Exam12.DAT, Exam12.INF, and Exam12.DIS. The output file created by *WRAP-HYD* includes *IN* records for all nine control points. The streamflow input file is shown alternatively as an INF file in standard format and as a HYD file in the optional six flows per record format.
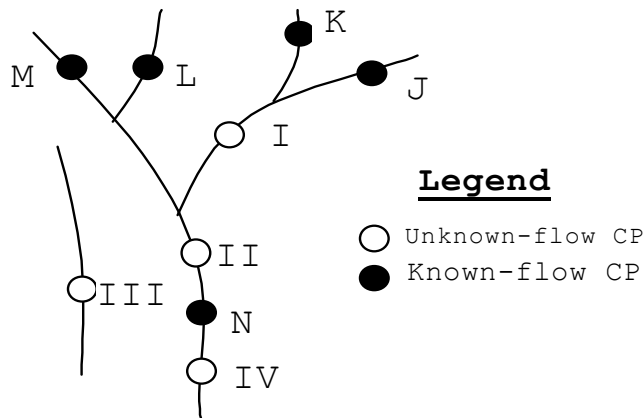
System Schematic for Example 12

WRAP-HYD DAT Input File for Example 12

```
**   WRAP-HYD Input File Exam12.DAT
**   Example 12 from Appendix H of WRAP Reference Manual
**
FO     1       0     1       0       1       1       1
JC     2    1996     1       1                                             3
**
CP  CP-J    CP-I       0       0       0
CP  CP-K    CP-I       0       0       0
CP  CP-L   CP-II       0       0       0
CP  CP-M   CP-II       0       0       0
CP  CP-N   CP-IV       0       0       0                                0.40
CP  CP-I   CP-II       0       0       4
CP CP-II    CP-N       0       0       8                                0.25
CPCP-III     OUT       0       0       3
CP CP-IV     OUT       0       0       4
**
ED
```

WRAP-HYD FLO Input File for Example 12

```
**    WRAP-HYD Input File Exam12.FLO
**    Example 12 from Appendix H of WRAP Reference Manual
**
IN  CP-J   1996   4000    4000    4000    4000    4000    4000    4000    4000    4000    4000    4000    4000
IN  CP-K   1996   5000    5000    5000    5000    5000    5000    5200    5200    5200    5200    5200    5200
IN  CP-L   1996   6500    6500    6500    6500    6500    6500    7500    7500    7500    7500    7500    7500
IN  CP-M   1996   6000    6000    6000    6000    6000    6000    8000    8000    8000    8000    8000    8000
IN  CP-N   1996  50000   50000   50000   50000   50000   50000   50000   50000   50000   50000   50000   50000
**
IN  CP-J   1997   4000     400      40       0      80     500    1000    2000    3000    4000    5000    6000
IN  CP-K   1997   5000     500      50       0      90    1000    5200    5200    5200    5200    5200    5200
IN  CP-L   1997   6500     650     500       0     500     500    7500    7500    7500    7500    7500    7500
IN  CP-M   1997   6000     600      60       0     100     900    8000    8000    8000    8000    8000    8000
IN  CP-N   1997  50000    5000     500       0     500     100  100000       0       0     100    8000   50000
```

WRAP-HYD HYD Input File for Example 12

(This file in the old *WRAP3* format may be used as an alternative to the INF file Exam12.INF.)

```
**    WRAP-HYD Input File Exam12.HYD
**    Example 12 from Appendix H of Reference Manual
**    Inflow IN and evaporation EV records in
**    the optional HYD file format.
**
IN  CP-J   1996    4000    4000    4000    4000    4000    4000
IN                 4000    4000    4000    4000    4000    4000
IN  CP-K   1996    5000    5000    5000    5000    5000    5000
IN                 5200    5200    5200    5200    5200    5200
IN  CP-L   1996    6500    6500    6500    6500    6500    6500
IN                 7500    7500    7500    7500    7500    7500
IN  CP-M   1996    6000    6000    6000    6000    6000    6000
IN                 8000    8000    8000    8000    8000    8000
IN  CP-N   1996   50000   50000   50000   50000   50000   50000
IN                50000   50000   50000   50000   50000   50000
IN  CP-J   1997    4000     400      40       0      80     500
IN                 1000    2000    3000    4000    5000    6000
IN  CP-K   1997    5000     500      50       0      90    1000
IN                 5200    5200    5200    5200    5200    5200
IN  CP-L   1997    6500     650     500       0     500     500
IN                 7500    7500    7500    7500    7500    7500
IN  CP-M   1997    6000     600      60       0     100     900
IN                 8000    8000    8000    8000    8000    8000
IN  CP-N   1997   50000    5000     500       0     500     100
IN               100000       0       0     100    8000   50000
```

WRAP-HYD DIS Input File for Example 12

```
**   WRAP-HYD Input File Exam12.DIS
**   Example 12 from Appendix H of Reference Manual
**
**   Flow distribution FD records
**
FD  CP-I     CP-N        2    CP-J    CP-K    CP-L    CP-M
FD CP-II     CP-N        4    CP-J    CP-K    CP-L    CP-M
FDCP-III     CP-N        0    CP-J    CP-K    CP-L    CP-M
FC 0.509
FD CP-IV     CP-N       -1
**
**   Watershed parameter WP records
**
WP  CP-J     60.        80     30.
WP  CP-K     75.        76     30.
WP  CP-L    100.        78     31.
WP  CP-M     90.        75     31.
WP  CP-N    600.        79     31.
WP  CP-I    225.        77     31.
WP CP-II    500.        78     31.
WPCP-III    140.        72     32.
WP CP-IV    800         78     31
ED
```

WRAP-HYD FLO Output File for Example 12

```
WRAP-HYD Output File Exam12out.OUT


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

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


Watershed Parameters from WP Records

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

WRAP-HYD FLO Output File for Example 12

```
WRAP-HYD Output File Exam12out.FLO

IN  CP-J    1996  4000.0  4000.0  4000.0  4000.0  4000.0  4000.0  4000.0  4000.0  4000.0  4000.0  4000.0  4000.0
IN  CP-K    1996  5000.0  5000.0  5000.0  5000.0  5000.0  5000.0  5200.0  5200.0  5200.0  5200.0  5200.0  5200.0
IN  CP-L    1996  6500.0  6500.0  6500.0  6500.0  6500.0  6500.0  7500.0  7500.0  7500.0  7500.0  7500.0  7500.0
IN  CP-M    1996  6000.0  6000.0  6000.0  6000.0  6000.0  6000.0  8000.0  8000.0  8000.0  8000.0  8000.0  8000.0
IN  CP-N    1996 50000.0 50000.0 50000.0 50000.0 50000.0 50000.0 50000.0 50000.0 50000.0 50000.0 50000.0 50000.0
IN  CP-I    1996 18513.8 18513.8 18513.8 18513.8 18513.8 18513.8 17970.5 17970.5 17970.5 17970.5 17970.5 17970.5
IN CP-II    1996 45901.5 45901.5 45901.5 45901.5 45901.5 45901.5 47317.2 47317.2 47317.2 47317.2 47317.2 47317.2
INCP-III    1996 17242.4 17242.4 17242.4 17242.4 17242.4 17242.4 16020.8 16020.8 16020.8 16020.8 16020.8 16020.8
IN CP-IV    1996 43852.0 43852.0 43852.0 43852.0 43852.0 43852.0 43852.0 43852.0 43852.0 43852.0 43852.0 43852.0
IN  CP-J    1997  4000.0   400.0    40.0     0.0    80.0   500.0  1000.0  2000.0  3000.0  4000.0  5000.0  6000.0
IN  CP-K    1997  5000.0   500.0    50.0     0.0    90.0  1000.0  5200.0  5200.0  5200.0  5200.0  5200.0  5200.0
IN  CP-L    1997  6500.0   650.0   500.0     0.0   500.0   500.0  7500.0  7500.0  7500.0  7500.0  7500.0  7500.0
IN  CP-M    1997  6000.0   600.0    60.0     0.0   100.0   900.0  8000.0  8000.0  8000.0  8000.0  8000.0  8000.0
IN  CP-N    1997 50000.0  5000.0   500.0     0.0   500.0   100.0100000.0     0.0     0.0   100.0  8000.0 50000.0
IN  CP-I    1997 18513.8  1536.5    90.0     0.0   170.0   100.0 31670.9     0.0     0.0   100.0  8000.0 19508.0
IN CP-II    1997 45901.5  4318.9   650.0     0.0   770.0  2900.0 83526.2 22700.0 23700.0 24700.0 25700.0 48203.5
INCP-III    1997 17242.4  1724.2     6.4     0.0     0.0     0.0 42616.0     0.0     0.0     0.0     0.0 15257.3
IN CP-IV    1997 43852.0  3953.2   318.4     0.0   318.4    60.0 89383.5     0.0     0.0    60.0  6506.8 43852.0
```